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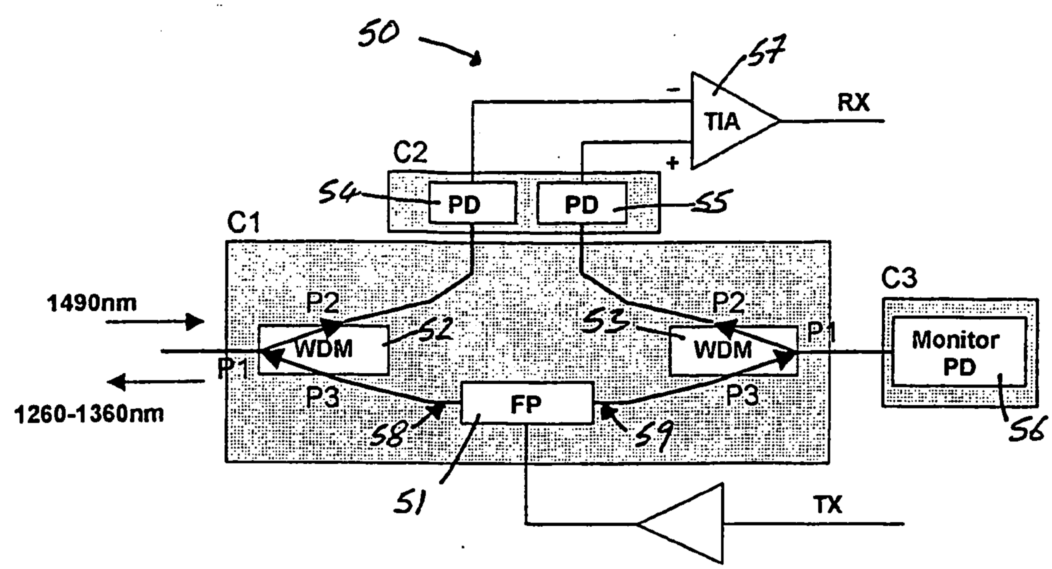


(57) Abstract: A optical transceiver that employs matched pairs of photonic components, including laser diodes, photodiodes and filters, and differential electrical compensation with common mode rejection to achieve a high effective level of optical and electrical isolation between signals at the transmitter waveband and signals at the receiver waveband. A novel configuration of WDM filter also improves isolation and both techniques are extended to the triplexer transceiver. Innovative arrangement of the components and contacts permits the realization of a very compact packaged transceiver unit.

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*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

# OPTICAL TRANSCEIVER

## Field of the Invention

The present invention relates to a compact optical transceiver with superior optical and electrical isolation and, in particular, to the use of differential compensation.

## Background to the Invention

The sharp increase in Internet usage has generated a strong and robust demand for high-speed access networks to customers' premises (fiber-to-the-home, fiber-to-the-business, etc). In addition to realizing stable high-speed and large-capacity communication, optical access networks have to break into an environment that is very cost sensitive and therefore requires a big reduction in the associated cost of optical fibre and components.

The Passive Optical Network (PON) architecture has been viewed favorably as one of the promising candidates for the access network. One of the key elements for the deployment of PON is the optical transceiver, which has simultaneously the capability to emit, receive and also discriminate between the two optical wavelengths used. In the most basic configuration, two optical fibers are necessary for optical communication, with one fibre for each direction. However, this two optical fibre requirement is not economical, and also wastes huge space in order to accommodate the optical fibre connection.

In order to reduce the number of fibres required in such systems, bi-directional communication can be used, as illustrated in Figure 1. In this configuration 10, two widely separated wavelengths (typically 1480-1600nm in one direction, and 1260-1360nm for another direction) are carried on a single fiber. The downstream data 11 from the central office, at the Optical Line Terminal (OLT) 12, is transmitted in the 1490nm wavelength band, while the upstream transmission 13 from the customer premise, the so-called Optical Network Unit (ONU) 14, is based on the 1310nm wavelength band.

Moreover, in more recent fiber-to-the-home applications, three wavelengths are considered (ITU-T G.983.3), where the wavelength bands 1480-1500nm and 1260-1360nm carry data signals in opposite directions, and a third wavelength band 1539-1565nm carries broadcast signal (such as CATV signal) in one direction. In this case, a simplepackage needs to be provided, which can house a laser light source, two receiver photodiodes and two WDM (wavelength division multiplexing) filters.

In order to economically realize this type of PON system, and to reduce the size of the system, a laser light source, photodiodes, and the WDM filters need to be integrated

to one compact package, while meeting the performance specifications defined in the international standards.

For a typical optical transceiver, the mean transmitter output power from the laser source is around +2dBm, while the receiver sensitivity should be at least –30dBm. Therefore, if a signal-to-noise ratio of at least 15dB is assumed, it becomes necessary to suppress both the optical and electrical cross-talk down to around –47dB (2+30+15=47). This stringent requirement is not easy to meet, and either higher electrical or/and optical cross-talk will compromise the operation of the transceiver.

In a prior art system shown in Figure 2, the transceiver 20 comprises a laser diode packaged in a transistor outline (TO) can 21 with, a TO-packaged photodiode 22, a WDM filter (beam splitter 23), and a glass lens 24, all assembled together in a single package coupled to an optical fibre 25. The WDM filter 23 separates the outgoing light from the incoming light, based on the difference of wavelengths. The drawbacks of this approach are: firstly, because of the use of bulk optics, the package size is large, secondly it requires separate optical alignment for both the laser and a photodiode, and thirdly it requires separate TO cans for a laser 21 and a photodiode 22 and also precision bulk optics, making the package cost higher. The stringent optical isolation requirement also places a constraint as to how close the transmitter and receiver chips can be mounted to realize a more compact module.

In another configuration used in a prior art, a compact hybrid monolithic integration on a silicon optical bench 31 is used. Figure 3 shows the schematic of the module's optical subassembly 30. In this case, the 1.3μm transmission light is generated by a laser diode 32, coupled into an optical waveguide 33 and then passes through a WDM filter 34 before being coupled into a single mode optical fibre 35, which is overlaid with glass 36 and has a ferrule 37 for assembly. On the other hand, the 1.55μm light to be received exits the optical fibre 35, is coupled into the optical waveguide 33 and then reflected by the WDM filter 34 before being detected by the 1.55μm photodiode 38, and the resulting signal amplified by a pre-amplifier 39. However, optical coupling between the optical waveguide 33 and the optical fibre 35 or between the laser diode 32 and the optical waveguide 33 is not very high. Therefore, there is a large power loss for the outgoing 1.3μm laser light as well as incoming 1.55μm light. More importantly, the power loss for the incoming light results in poor receiver sensitivity, which is the crucial parameter for this type of optical system.

As shown in Figure 4(a), a further prior art system 40 utilizes even more compact monolithic integration, whereby a laser diode 41 having a grating rear reflector, a wavelength-selective absorbing section 42, and a photodiode 43, are monolithically

tegrated on the same Indium Phosphide (InP) substrate 44, and the whole assembly, including a preamplifier 45, is packaged into a small module 46, as shown in Figure 4(b). The 1.3μm laser light is emitted directly from the laser facet, while the light exiting the laser section 41 in the other direction, via the grating reflector, is partially reflected by the grating and partially absorbed by the absorbing section 42, which comprises the same material as the laser diode 41. The incoming 1.55μm light is coupled into the laser first 41, passes through the absorber 42, and finally fed into the photodiode 43. The absorbing section does not absorb very much of the 1.55μm light. The drawbacks of this known approach are: firstly, the efficiency of coupling the 1.55μm incoming light into the laser section is not large (typically 20-30%); secondly, the incoming 1.55μm light is partially absorbed in the absorbing section; thirdly, optical isolation between the laser and the photodiode is not large enough, resulting in high cross-talk; and fourthly, the electrical isolation and cross-talk is not low enough, as the laser and the photodiode are fabricated in relatively close proximity on the same InP substrate.

From the above, it is clear that simple monolithic/hybrid integrated photonic integrated circuit (PIC)-based solutions are not able to meet the electrical and optical cross-talk requirements. The working alternative is that based on precision bulk optics, which results in a large module and requires strict alignment of both the transmitter and receiver in a 90° relative orientation. Packaging and mounting of such a module is not easy. As a result, the expensive and stringent manufacturing processes involved means that it is very difficult to realize a cost-competitive solution.

**Summary of the Invention**

According to a first aspect of the present invention, an optical transceiver comprises:

an optical port for coupling optical signals into and out of the optical transceiver;

a first optical transmitter for generating an optical output signal at a first wavelength in dependence on an electrical driving signal;

a first optical receiver for detecting an optical input signal at a second wavelength, the optical receiver generating an electrical received signal in dependence on the optical input signal; and,

means for compensating for an electrical error signal, the error signal being generated by the optical receiver in dependence on a portion of the optical output signal detected at the first wavelength and added to the electrical received signal.

In this manner, any contribution to the overall electrical received signal generated by the receiver that derives from stray transmitter light detected by the receiver can be compensated for by an equal and opposite electrical signal derived solely from the transmitter light. As a result, a high level of "effective" optical and electrical isolation between the transmitter and receiver can be achieved in the transceiver by post-detection processing of the electrical signals.

Preferably, the compensating means comprises:

a second optical receiver for generating an electrical correction signal in dependence on a portion of the optical output signal detected at the first wavelength; and,

means for combining the electrical correction signal with the electrical received signal and error signal such that, in use, the electrical error signal is substantially compensated for.

Alternatively, the compensating means comprises:

a second optical transmitter for generating an optical correction signal at the first wavelength in dependence on the electrical driving signal;

a second optical receiver for generating an electrical correction signal in dependence on the optical correction signal; and,

means for combining the electrical correction signal with the electrical received signal and error signal such that, in use, the electrical error signal is substantially compensated for.

Thus the necessary correction of the electrical signals can be achieved either by anti-phase addition of signals form a "mirror" pair of photodiode receivers or else by driving a "mirror" pair of laser transmitters in antiphase and adding the signals resulting form detection by a "mirror" pair of photodiode receivers. The appropriately phased addition of the electrical signals may be achieved by using a summing or differential amplifier.

According to a second aspect of the present invention, an optical transceiver comprises:

an optical port for coupling optical signals into and out of the optical transceiver;

an optical transmitter for generating an optical output signal at a first wavelength in dependence on an electrical driving signal;

an optical receiver for detecting an optical input signal at a second wavelength, the optical receiver comprising a photodetector formed on a receiver substrate, the photodetector generating an electrical received signal in dependence on the optical input signal; and,

a wavelength division multiplexing (WDM) filter for routing the optical output signal from the transmitter to the optical port and for routing the optical input signal from the optical port to the receiver, the WDM filter comprising a thin film filter disposed on the receiver substrate, the receiver substrate disposed at an angle of substantially 45 degrees to a plane containing the transmitter.

In this manner, the transceiver comprises a composite receiver-demultiplexer which both simplifies the device aallowing it to be more compact.

Preferably, the photodetector and the thin film WDM filter are disposed on an upper surface of the receiver substrate and an optical coating that is reflective at the second wavelength is disposed on a lower surface of the substrate such that, in use, the optical input signal diffracted through the thin film filter and reflected by the optical coating towards the photodetector.

This arrangement improves optical isolation between the transmitter and receiver by providing additional spatial and angular separation of the optical paths for the output and input signals. The concept can be extended to a triplexer transceiver in which the input signal comprises signals at two different wavelengths, which must be demultiplexed and detected by separate receivers. Furthermore, the differential electrical correction technique employed in the transceiver according to the first aspect may also be used for additional effective isolation.

**Brief Description of the Drawings**

Examples of the present invention will now be described in detail with reference to the accompanying drawings, in which:

Figure 1 illustrates bi-directional communication between the central office (OLT) and a customer premises (ONU);

Figure 2 shows a known transceiver system using bulk optics;

Figure 3 shows a known transceiver system utilizing hybrid integration on a Si optical bench;

Figure 4A shows a known transceiver system utilizing monolithic integration of a laser diode, an absorbing section and a photodiode;

Figure 4B shows a module incorporating the monolithically integrated chip shown in Figure 4A;

Figure 5 shows a first embodiment of an optical transceiver according to the present invention;

Figure 6 shows a second embodiment of an optical transceiver;

Figure 7 shows the application of QWI to an optical transceiver of the type shown in Figure 6;

Figure 8 shows a third embodiment of an optical transceiver;

Figure 9 shows a fourth embodiment of an optical transceiver;

Figure 10 shows the overall configuration of a fifth embodiment of an optical transceiver;

Figure 11 illustrates the separate FP/MPD and PD chips for a transceiver of the type of shown in Figure 10;

Figures 12A and 12B show, respectively, a plan view and side view of a TOSA packaging for the type of transceiver shown in Figure 10;

Figure 13 shows a sixth embodiment of the type of an optical transceiver;

Figure 14 shows a seventh embodiment of an optical transceiver;

Figure 15 shows an eighth embodiment of an optical transceiver;

Figure 16 illustrates the physical chip layout and mounting for the type of transceiver shown in Figure 15;

Figures 17A and 17B show, respectively, a plan view and side view of a TOSA packaging for the type of transceiver shown in Figure 15;

Figure 18A shows a perspective view of a PD/WDM-filter chip for the type of transceiver shown in Figure 15;

Figure 18B shows the epitaxial layer structure of the PD/WDM-filter chip shown in Figure 18A;

Figure 19 shows a ninth embodiment of an optical transceiver;

Figures 20A and 20B show, respectively, a plan view and side view of the physical chip layout and mounting for the type of transceiver shown in Figure 19;

Figure 21 shows a tenth embodiment of an optical transceiver;

Figures 22A and 22B show, respectively, a plan view and side view of the physical chip layout and mounting for the type of transceiver shown in Figure 21;

Figure 23 shows the detailed structure of a PD/WDM-filter chip for the type of transceiver shown in Figure 21;

Figure 24 shows a drive circuitry for the FP laser diodes, monitor and receiver photodiodes for the type of transceiver shown in Figure 21;

Figures 25A and 25B show, respectively, a plan view and side view of a TOSA packaging for the type of transceiver shown in Figure 21;

Figure 26 shows a side view of the physical layout and mounting of an eleventh embodiment of an optical transceiver;

Figures 27A and 27B show, respectively, a plan view and side view of a TOSA packaging for the type of transceiver shown in Figure 26;

Figure 28 shows the detailed structure of a PD/WDM-filter chip for a twelfth embodiment of an optical transceiver; and,

Figure 29 shows the detailed structure of a PD/WDM-filter chip for a thirteenth embodiment of an optical transceiver;

**Detailed Description of the Invention**

In the present invention, new designs are provided for a compact optical transceiver module with improved electrical and optical isolation performance, such that it could meet the requirements of PON with speeds of 1Gbps and above. In describing the following embodiments, we will be focusing on the optical transceiver at the customer premise, the ONU. However, the same concept could equally be applied to that at the central office, at the OLT.

As pointed out above, electrical and optical isolation of the two wavelengths of light, namely the 1310nm band and the 1490nm band, is critical, especially at the receiver photodiode (PD). Preferably, the receiver PD should only be sensitive to the downstream 1490nm light, and not to the 1310nm upstream light. However, as a result of the close proximity of the 1310nm transmitter light source, e.g. a Fabry-Perot (FP) laser diode, and the receiver PD in the ONU transceiver, as well as the strength of the transmitter signal versus the weakness of the receiver signal, it is not possible to completely eliminate the effect on the receiver PD of stray 1310nm light.

In the present invention, an electrical cancellation method is provided to improve the cross-talk achievable in a compact optical transceiver module. Here, a balanced receiver interface is incorporated, which comprises a pair of receiver PDs with matching performance connected up to the differential inputs of a transimpedance amplifier (TIA). By using a differential operation at the TIA, it is possible to null out unwanted common signals incident onto the receiver PD pair through common mode rejection (CMR). An alternative scheme employs a pair of matched FP laser diodes and which are driven in a differential manner, such that the effect of the 1310nm light is cancelled out when the signals from the receiver PD pair are summed by the TIA. These schemes greatly enhance the electrical and optical isolation between the two wavelengths of light in the ONU transceiver, realizing an isolation improvement of more than 20dB.

The invention is based on matched-performance FP laser diode pairs for light generation, and photodiode pairs for 1490nm light detection and 1310nm light monitoring. This requirement for good matching of photonic components is easily met with the tolerances currently available in semiconductor wafer manufacturing processes, as the performance variation between two neighboring dies is minimal. In addition, the temperature-dependent characteristics of the neighboring devices are expected to be

milar too. More importantly, a matched device pair located on a single compact chip means efficient temperature tracking between the devices, ensuring matched performance across the entire operating temperature range. Furthermore, ageing characteristics of the matched pairs are also expected to be similar and, as a consequence, electrical and optical isolation in the transceiver will not degrade with time.

The design flexibility realizable in a transceiver according to the present invention allows the optical parts to be placed in very close proximity, while not compromising the electrical and optical isolation requirements. This leads to a very compact module with low material cost and low manufacturing cost, as illustrated in the transmitter optical subassembly (TOSA) packages shown in Figures 12, 17, 25 and 27.

In the first embodiment of a transceiver 50 according to the present invention shown in Figure 5, three separate chips are used, namely chip C1 with the FP laser diode 51 and two sets of WDM filters 52, 53, chip C2 with a receiver PD pair 54, 55 and chip C3 with a monitor PD 56. Light from the FP laser diode 51 is tapped out from both facets 58, 59 and guided into ports P3 of the WDM filters 52, 53. This light exits the WDM filters through ports P1 on the first chip C1, and is either coupled into an optical fibre for onward transmission or is incident onto the monitor PD 56 on chip C3. The incoming signal at a wavelength 1490nm is guided from port P1 to port P2 of the WDM filter 52 and then onto a receiver PD 54 element on chip C2.

Due to the imperfect filtering operation, some of the 1310nm light will be coupled out via ports P2 of the WDM filters. Furthermore, this unwanted stray 1310nm light is guided into the receiver PD 54, degrading the optical isolation. However, according to the present invention the transceiver comprises a pair of receivers 54, 55, which are connected to the differential inputs of a trans-impedance amplifier (TIA) 57. In this way, the undesired 1310nm light is rejected, since it appears as the common signal from the receiver PD pair. In addition, by separating the FP laser diode/WDM filter arrangement from the receiver PD pair and locating them on two separate chips, electrical isolation is also very much improved. By ensuring good matching of the two outputs (front 58 and back 59) from the FP laser, and also the WDM filter pair 52, 53, waveguides and receiver PD pair 54, 55 an isolation improvement of better than 20dB can be achieved. Together with the typical 20dB filtering performance from the WDM filter, a much reduced optical and electrical cross-talk for the transceiver is possible.

In the second embodiment of the optical transceiver 60, shown in Figure 6, there are again three chips, but chip C1 now contains a pair of identical FP laser diodes 61, 62 and two WDM filters 63, 64. In this configuration, the laser driver TX 65 drives the FP laser diode pair 61, 62 using a differential mode operation. The 1310nm light from the upper FP laser diode 61 is guided to port P3 of the WDM filter 63, which will then exit at

ɔrt P1 to an optical fibre. Similarly, the output light from the lower FP laser diode 62 passes through port P3 and then P1 of the WDM filter 64 to a monitor PD 66. The 1490nm incoming signal light enters the transceiver 60 through port P1 of the upper WDM filter 63 and is filtered to port P2 and thereafter is guided to the upper receiver PD 67.

Here, coupling the ports P2 of the WDM filters 63, 64 to the receiver PD pair 67, 68 located on chip C2, and feeding the electrical output signals from the receiver PD pair as positive inputs to a TIA 69, nulls out any undesired 1310nm light signals originating from the differentially driven FP laser diode pair. This allows very good optical isolation to be achieved between the incoming 1490nm light and the outgoing 1310nm light. Of course, in a similar manner to the first embodiment, the use of the separate chip design ensures good electrical isolation.

Optical isolation between the 1490nm and 1310nm light in the transceiver 70 can be further enhanced by introducing quantum well intermixing (QWI) to certain locations of chip C1, as shown in Figure 7. Here, the device is initially grown so as to be absorbing at 1310nm. The waveguides leading from the FP laser diode pair 71, 72 and the WDM filter pair 73, 74 are then QW intermixed, as indicated, to render them transparent to 1310nm light. The as-grown non-intermixed waveguides from port P2 of WDM filters 73, 74 to the receiver PD pair 77, 78 remain absorbing to the 1310nm unwanted light, whereas the incoming 1490nm light is not absorbed by any of the waveguides in chip C1. Consequently, the optical isolation between the 1490nm signal light and unwanted 1310nm light at the PDs is improved by an additional 10~20dB. Details of the application of QWI to absorption control are given in a co-pending International patent application, Agent's reference PJF01601WO.

Figure 8 shows a third embodiment of a transceiver 80 in which the matched FP laser diode pair 81, 82 and receiver PD pair 83, 84 are retained, but the WDM filter set is eliminated. Here, 1310nm light, emitted from the front facets of the well-matched FP laser diode pair, is guided to an output optical fibre and a monitor PD 85, respectively. Light emitted from the back facets of the FP laser diode pair is routed via other waveguides towards the receiver PD pair 83, 84 in chip C2. The 1490nm signal light is coupled into chip C1, and then transmitted along a waveguide (transparent to 1490nm light) through the FP laser 81 and out towards the receiver PD for detection. The electrical output signals from the receiver PD pair 83, 84 are fed to the positive inputs of a TIA 86. Again, by driving the FP laser diode pair in differential mode operation 87, the unwanted common 1310nm signals detected by the PD pair 83, 84 are easily cancelled by simple addition and common mode rejection.

Employing the QWI technique can make further gains in isolation. The waveguides leading from the back facets of the FP laser diode pair 81, 82 can be

ndered absorbing to light at 1310nm by designing the epitaxial layer structure of chip C1 to absorb 1310nm light. The remaining portion of chip C1 is then QW intermixed for emission at 1310nm by the FP laser diode pair 81, 82 and for transparency in the front waveguides. In this way, the back propagating 1310nm light from the FP laser diode pair will be absorbed by the non-intermixed waveguides leading from the back facets towards the PD pair 83, 84, greatly enhancing the optical isolation.

It should be noted that, although this compact configuration is based on a simple "in-line" photonic IC structure, the serious cross-talk problem has been solved by implementing differential compensation to reject the unwanted 1310nm light signal, using a well-matched FP laser diode pair and receiver PD pair. Together with the absorbing passive waveguides located after the FP laser diode pair, overall cross-talk in the transceiver is reduced to the required level of –50dB.

The above configuration can be further simplified by adopting common-phase driving 97 of the FP laser diode pair 91, 92, resulting in the transceiver 90 of the fourth embodiment shown in Figure 9. The three-chip design is similar to that shown in Figure 8. However, here the electrical output signals from the receiver PD pair 93, 94 are connected, respectively, to the positive and negative inputs of the TIA 96. In this embodiment, the unwanted 1310nm light from the FP laser diode pair 91, 92 is again guided to the receiver PDs 93, 94. However, with the TIA 96 employed in a differential configuration, the unwanted 1310nm light signal is cancelled by CMR, thereby improving the effective optical isolation. In a similar manner to the third embodiment, the combination of the differential detection scheme and passive waveguides that absorb most of the unwanted 1310nm allows the transceiver 90 to meet the required level of cross-talk.

Figure 10 shows a fifth embodiment of an optical transceiver 100 based on a combination of those shown in Figures 8 and 9. Also shown is the layout of the CMOS analog integrated circuit (IC) 105 used to drive both the transmitter and receiver parts of the transceiver. A single-phase drive (DRV) is used to operate the FP laser diode pair 101, 102, while the electrical output signals from the receiver PD pair 103, 104 are connected for differential amplification so that the undesired 1310nm light signal is cancelled out. In this arrangement, each PD 103, 104 has an associated TIA (TIA1, TIA2), the output from which is fed into a differential amplifier106. Furthermore, a pair of in-line monitor photodiodes (MPDs) 107, 108 is included, which provide additional signal information that can be processed and used to enhance still further the quality of CMR.

The receiver part of the circuitry consists essentially of transimpedance amplifiers (TIAs) as the main building blocks, but also includes low pass filters (LPF1, LPF2), Gilbert-cell mixers (MLT1, MLT2) and simple linear functional blocks (F1, F2). These

ɔmponents are used to process the signals from the MPDs. In particular, the linear functional blocks (F1, F2) are used to implement a linear scaling function, such as $Ax+B$, where $x$ is the input and $A$ and $B$ are variable controls. This provides the necessary control to ensure an even higher degree of common mode rejection using the differential 106 detection scheme. The transmitter part of the circuitry comprises a PMOS driver with bias setting, and p-side driving of FP laser diode pair is employed.

Figure 11 illustrates the actual physical layout of the components for this fifth embodiment of a transceiver 110. The FP laser diode pair (FP1, FP2) and MPD pair (MPD1, MPD2) are located on one chip and the PD pair (PD1, PD2) is located on another chip. It should be noted that the monitor PD pair (MPD1 and MPD2) are low frequency, side-illuminated waveguide photodiodes, while the receiver PD pair (PD1 and PD2) are top-illuminated devices with a frequency bandwidth of up to 2.5Gb/s. The single electrode 117 in between the FP laser diode pair is the common drive electrode, while the electrodes 112, 113 for each of the monitor PDs are located on either side of the FP/MPD chip. A partial reflector, consisting of an etched groove 114, for example, is required at the rear of the FP laser diode pair to form the back facet. The front facet 115 of the FP laser diode pair has an optimized optical coating such that it is of intermediate reflectivity for 1310nm light but of low reflectivity for the incoming 1490nm signal light. An insulating region is required between the FP laser diode pair and the monitor PD pair (ATT) and this could be realized by silicon implantation, to ensure good electrical isolation.

The two top-illuminated receiver PDs are located on the PD chip and each one has two electrodes 116, 117 for the n and p contacts. As shown in Figure 11, the two FP/MPD and PD chips are mounted in a 90° configuration, i.e. perpendicular to one another, so as to achieve minimum electrical interference between the devices. The two chips are preferably arranged with a spacing of 50 to 100μm between them.

The whole two-chip assembly, comprising FP laser diode pair, monitor PD (MPD) pair, and receiver PD pair, is mounted inside a 6-pin TOSA package. Figures 12A and 12B illustrate, respectively, the top view and side view of the mounting configuration 120 for the FP/MPD 121 and PD 122 chips within the TOSA package, and also the arrangement of bonding wires made between the chips and the pins of the TOSA package. A careful disposition of the devices, pins and bonding wires within the package helps to minimize electrical interference within the package. In particular, a uniform circumferential arrangement of bonding wires and pins, as shown in Figure 12A, ensures very good electrical isolation between the different light-emitting and light-detecting devices.

Figure 13 shows a sixth embodiment of a transceiver 130, which is a modified form of the configuration shown in Figure 8. Here again, two separate chips are employed, with the FP laser diode pair 131, 132 and monitor PD (MPD) pair 133, 134 monolithically integrated in chip C1. As in the previous configuration, the epitaxial layer structure of chip C1 is designed and grown to be absorbing for 1310nm light. The region of the FP laser diode pair 131, 132 is then QW intermixed to change its bandgap for emission at 1310nm. Similarly, the front waveguides of the FP laser diode pair are rendered transparent. The monitor PD pair 133, 134 is formed from part of the waveguides that lead away from the rear of the FP laser diode pair. As this region is not QW intermixed, it is capable of absorbing and detecting the 1310nm light. The monitor PD pair is designed for low speed operation, as it is used only to monitor the FP laser output power.

Although the incoming 1490nm signal light has to pass through the FP laser diode region 131, 132 and monitor PD region 133, 134, there is no absorption as both the intermixed and non-intermixed regions in chip C1 are transparent to the 1490nm light. The differentially driven 135 operation of the FP laser diode pair 131, 132, together with the connection of the receiver PD pair 136, 137 to the positive inputs of the TIA 138, results in any small remaining signal due to back-propagating 1310nm light signal being rejected, enabling the realization of the required levels of electrical and optical cross-talk. By using the signal from the monitor PD pair 133, 134 in this configuration, the performance of the FP laser diode pair is sensed and this allows dynamic balancing of the optical performance of the two FP lasers 131, 132. Compensation for any performance mismatch between the two FP laser diode elements, and also deviations due to unequal ageing, can easily be effected.

A seventh embodiment of a transceiver 140 is shown in Figure 14, and is a simplified variation on the embodiment shown in Figure 10. In this in-line arrangement, there is no "mirroring" of components, which instead comprises a single 1310nm FP laser diode 141, high speed monitor photodiode for 1310nm light (PD1) 142 and receiver PD (PD2) 143 for 1490nm light, fabricated on two separate chips, C1 and C2, as in previous embodiments. It should be noted that the two photodiodes 142, 143 have to be capable of high-speed operation, and monitor PD1 142 is to absorb only 1310nm light, while the receiver PD2 143 absorbs the 1490nm signal and any unwanted 1310nm leakage light. As in previous examples, the device is grown to be absorbing for 1310nm light, and the region of the FP laser diode 141 and input waveguide are QW intermixed, leaving the waveguide behind the FP laser diode 141 non-intermixed and absorbing for the 1310nm light.

The output of the monitor PD1 144 is fed to a TIA 144, and the resulting signal passed through a variable attenuator (ATT) 145. As usual, the output signal from the

:ceiver PD2 143 is also fed into a TIA 146. The outputs from the two TIAs 144, 146 are connected to an amplifier 147 in a differential mode of operation. Furthermore, a portion of the monitoring signal derived from the 1310nm light is tapped out 148 after the TIA 144 before the signal enters the variable attenuator (ATT). As the single FP laser diode 141 and monitor PD1 142 are monolithically integrated on chip C1, the driver for the FP laser 141 has to be based on a PMOS design in order to accommodate the reverse-biased PD1 142.

In this configuration, the monitor signal from PD1 142 is calibrated so as to cancel the effect of the unwanted 1310nm light detected by receiver PD2 143. Here, while the FP laser diode 141 is operating and emitting 1310nm light, and in the absence of a 1490nm input signal, the variable attenuator 145 is adjusted such that the RX signal is zero. This ensures to first order that the 1310nm signals from the monitor PD1 142 and receiver PD2 143 are effectively cancelled out. Hence, in normal operating conditions, electrical and optical isolation between the 1490nm signal light and unwanted 1310nm light can be effectively maintained. A further advantage of this configuration is that, by carrying out calibration at regular intervals, any degradation in the FP laser diode 141 performance resulting from ageing can be compensated for. This compact configuration of two separate chips with 3 devices allows the transceiver to be packaged inside a conventional 4-pin TO-can, or TOSA package, leading to a low cost optical transceiver.

Figure 15 shows an eighth embodiment of an optical transceiver 150, in which receiver sensitivity is much enhanced by employing a novel arrangement of PD with WDM filter. The design thus has something in common with those shown in Figures 5 and 6. However, as compared to all previous configurations, where the receiver PD pair is located after the FP laser diode pair, this configuration places the receiver PD pair (PD1, PD2) in front of the FP laser diode pair (FP1, FP2). Here, the receiver PD pair (PD1, PD2) is orientated at an angle of 45° with respect to the plane of the FP laser diode chip, as shown in the insert 151 to Figure 15. The top surfaces of the receiver PD pair (PD1 and PD2) are coated with a thin film WDM filter, such that the 1310nm band light from the FP laser diode pair is reflected and thereby re-routed to a direction normal to the plane of the FP laser diode pair, while the 1490nm incoming light passes through the thin film WDM filter to be absorbed by the receiver PD1. In this way, the requirements for the optical coating on the facets of the FP laser diode pair are much reduced, as the coatings only need to be designed for operation with the 1310nm light emitted by the laser diodes. Of course, in addition to these refinements, use of the differential amplification scheme 152 for the receiver PD pair, as shown in Figure 15, ensures effective optical and electrical isolation.

The configuration 160 of the receiver PD chip and the FP laser diode/monitor PD chip is shown in Figure 16. The monitor PDs are low frequency and have a ridge-based waveguide type structure, while the receiver PD pair (PD1, PD2) is of the top-illumination type, with a thin film WDM filter deposited on the upper surface. Good electrical isolation is implemented between the FP laser diode pair and monitor PD pair formed on the same chip. The two chips, receiver PD chip 161 and FP laser diode/monitor PD chip 162 are mounted on a specially designed metal submount 163, which acts as a heat sink as well as an electrical ground. It is noted that the PD-WDM-filter chip 162 is mounted on the 45°-inclined slope of the submount so that light emitted by the FP laser diodes on chip 161 is reflected so as to propagate in a direction that is normal to the incident direction and also aligned to the optical axis of the TOSA package in which the whole assembly is packaged, as shown in Figure 17. Figure 17 also shows the layout of the chips 171, bonding wires 172 and pins 173 within the package 170. The electrical connections for the various components are uniformly disposed around part of the circumference of the package. Moreover, the pins and wires for the matched PD pair PD1, PD2 are located symmetrically and at an orientation of 90° to those for the laser pair diode FP, in order to reduce electrical interference. Also shown is the light collecting lens 174 at the input to the TOSA package.

Figure 18A illustrates a design for the receiver PD-WDM filter chip and Figure 18B shows in more detail the structure 180 of the receiver PD with WDM filter coating, which achieves the requisite level cross-talk. As described above, the thin film WDM filter 181 serves to totally reflect the 1310nm light which is incident at an angle of 45° to its normal. On the other hand, the 1490nm incoming light is transmitted through the filter 181 to be absorbed and detected by the underlying photodiode. The receiver photodiode has a structure comprising a p-doped InGaAsP layer 182, which is absorbing at 1310nm, and an undoped i-InGaAs layer 183, both layers grown successively on an n-InP substrate 184. The InGaAsP 182 absorbing layer serves to absorb any residual 1310nm light that passes through the thin film WDM filter 181. With 15dB of filtering by the WDM filter 181, another 15dB of attenuation of the 1310nm light by the absorption layer 182 and finally 20dB of effective isolation provided by differential detection, the –50dB optical cross-talk target can be achieved.

As described before, electrical cross-talk within the receiver PD-WDM filter chip can be controlled by reducing inductive and capacitive coupling through 90° positioning of the wire bonding for the transmitter (FP laser diode pair) and receiver devices within the package. Further gains in electrical isolation can be made by employing capacitive shielding on the top surface of the receiver PD chip. Through these measures, 30dB of

ectrical cross-talk reduction can be achieved. This, together with the additional 20dB contribution from differential detection, allows the –50dB electrical cross-talk target to be met.

As shown in Figure 19, modification of the configuration described above leads to another embodiment for a transceiver 190. In this tenth embodiment, the FP/MPD chip is separated into two chips 191 and 192, with the FP laser diode pair located on one 191 and monitor PD pair on the other 192. Here, broad area waveguide, edge-coupled photodiodes (MPD1, MPD2) are employed for monitoring the ouput of the FP laser diodes (FP1, FP2). By locating the two types of devices in separate chips, the issue of electrical isolation between the FP laser diode and monitor PD is eliminated. In addition, optical alignment between the FP laser diode and monitor PD is no longer as critical, since the broad area waveguide-based structures used for the monitor PDs have a relatively wide acceptance angle. The receiver PDs are located on a third chip 193. The same drive and receiver circuitry can be employed as previously shown in Figures 10 and 15.

Figure 20A illustrates the physical layout of the three chips 202, 203, 204 for this tenth embodiment and Figure 20B shows 200 how they are mounted on a metal heat-sink 201. It is noted that the section of the metal heat-sink for mounting the monitor PD 203 is inclined away from the FP laser diode 204 section. This orientation is designed to maximize the optical overlap between the light propagating in the monitor PD pair and the absorption layer in the monitor PD. In a similar manner to the eighth embodiment, the required optical and electrical cross-talk levels are achieved here by the combination of differential detection, thin film WDM filter, absorptive InGaAsP layer within the receiver PD pair, an the appropriate mounting of components and layout of bonding wires within the TOSA package.

Figure 21 illustrates a tenth embodiment of a transceiver 210, in which use is again made of a receiver PD pair (PD1, PD2) with integral WDM filter, but which has different design, as will be described. Here, the two FP laser diodes (FP1, FP2) are driven in a differential mode of operation and a single monitor PD (MPD1) is used to collect and measure the sum of the optical output from the FP laser diode pair. The signal 211 derived from the monitor PD is fed back to the laser driver IC 212 and used to control the power of the laser diodes. In addition, the two receiver PDs are connected and linked to the input of a TIA. This, together with the differential driving 213 of the FP laser diode pair, ensures that any signal resulting from the unwanted 1310nm light incident on the receiver PD pair will be cancelled out. In this configuration, the electronic driver 212 and TIA 214 ICs are much simpler, and the use of differential driving for the FP laser diode pair also results in lower power consumption.

The layout of the three chips (PD-WDM filter chip 222, FP chip 223 and monitor PD chip 224) is illustrated in Figure 22A, whereas a side view of the mounting arrangement 220 is shown in Figure 22B. In this embodiment, the monitor PD is again provided by a broad area waveguide-based, side-illuminated structure that is designed to accept light from both of the two FP laser diodes. An n-type substrate can still be used for the receiver PD pair providing the electrical pad is located on top of a sufficiently thick layer of passivation dielectric, such as silicon nitride. All three chips are located on a single substrate 221.

Figure 23 shows the structure 230 of the receiver PD for this embodiment in detail. It is noted that the active absorbing InGaAs layer is only located at one end 231 of the chip. As before, a thin film WDM filter 232 reflects the outgoing 1310nm light from the FP laser diode and the InGaAsP layer absorbs any stray 1310nm light that penetrates the filter 232. In fact, the residual 1310nm light would not actually reach the light sensitive section 231, as this part is off-axis from the FP light path, thereby contributing to even greater isolation. Conversely, the incoming 1490nm light entering the TOSA package is converged by the optical lens of the package so as to fall onto the receiver PD section after propagation through the filter 232 and substrate 233 followed by reflection from the back surface 234 of the substrate. Optical isolation can be improved still further by coating the top of the PD with the p-contact metal so that any stray 1310nm light cannot enter into the absorbing InGaAs layer from this direction.

The simplified front-end electronics 240 for this embodiment are shown in Figure 24. Better sensitivity can be realized by using a single TIA for the receiver PD pair. Furthermore, by designing the FP laser diode chip with a p-type or semi-insulating substrate, a common +3.3V voltage line 241 can be adopted for the TIA IC 242 and driver 1C 243, which greatly simplifies the driver circuit as illustrated. Figures 25A and 25B illustrate, respectively, a top view and a side view of the mounting configuration for this optical transceiver within a 6-pin TOSA packaging 250. The receiver PD and FP laser diode bonding wires 251 and 252 are again oriented at 90° to each other to reduce interference. As there is only one monitor PD, there is an extra pin NC available, and this could be used as GND for an internally located TIA, making the whole package even more compact.

The configuration described in the tenth embodiment can be extended to accommodate an additional wavelength, such as the 1550nm light used as a carrier for CATV. Figure 26 shows an eleventh embodiment of a transceiver 260 in which the additional multiplexing is provided to realize a triplexer transceiver module. In this type of device, the incoming signal light consists of two wavelengths, 1490nm light and 1550nm light, which must be demultiplexed. As shown in Figure 26, this is achieved by fabricating

WDM filter 261 on a glass plate 262 to act as the demultiplexer. The WDM filter 261 could be based on a thin film multi-layered dielectric structure, or a micro-patterned hologram formed on the glass plate. The filter can be designed such that 1490nm and 1310nm light is transmitted through it, while 1550nm light is reflected so as to be incident onto a receiver PD chip 263. This receiver PD 264 for the 1550nm could be of a similar design to that used for detecting 1490nm light in the tenth embodiment, utilizing reflection from the lower face of the PD substrate 265 to route the signal to a InGaAs active layer located at one end of the chip 264. Again, an InGaAsP absorbing layer is included to absorb any stray 1310nm light.

Figures 27A and 27B illustrate, respectively, a top view and a side view of the mounting configuration 270 for this optical transceiver within a six-pin TOSA package. All of the six pins are utilized, with two for the FP laser diode pair (FP1, FP2), and one each for the monitor PD (MPD), the PD for 1550nm light and the PD for 1490nm light and one for the power line (+3.3V). Again, the bonding wire 271 of the receiver PD for 1490nm is arranged in an orientation close to 90° from those 272 for the FP laser diode in order to minimize interference. The wire for the 1550 nm receiver PD is located between these.

Figure 28 illustrates yet another, twelfth, embodiment for a triplexer transceiver 280, in which the demultiplexer and receiver PD structure are all formed on a single chip. In addition to reflecting the outgoing 1310nm light from the FP laser diode 281, the WDM filter 282 also demultiplexes and diffracts the 1490nm and 1550nm light into two different directions. By locating the receiver PDs 283, 284 at the focal points of the two diffracted signals, the demultiplexed signals can be detected separately and any stray 1310nm light is absorbed by the InGaAsP layer. In this design, the WDM filter could be realized as either a holographic or diffractive optical element fabricated by means of a dielectric thin film. The 1490 nm and 1550 nm light is reflected from the lower surface 285 of the substrate 286.

Figure 29 shows a thirteenth embodiment of a transceiver 290, in which demultiplexing of the 1490nm and 1550nm light incident on the triplexer transceiver is realized by cascading the receiver PDs for the two wavelengths. Here, one receiver PD chip 291 is bonded on top of another 292. The upper receiver PD chip 291 has the WDM filter 293 that reflects the outgoing 1310nm light and allows the incoming 1490nm and 1550nm light to pass through. The n-metal contact for the upper receiver PD 294 is accessed from the top surface. The WDM filter 295 of the lower receiver PD chip 292 reflects the 1490nm light, re-routing it towards the upper receiver PD 294, where it is incident onto the InGaAs absorber layer located in the upper receiver PD 294. At the same time, the 1550nm light passes through the lower WDM filter 295 and is reflected by the mirror-coated lower surface 296 of the lower receiver PD chip 292 and re-routed

wards the InGaAs absorber layer of the lower receiver PD 297, where it is detected. Consequently, the two wavelengths of incoming light are demultiplexed and routed by two separate receiver PD chips. Similarly to the previous configurations, any stray 1310nm light is absorbed by the InGaAsP absorption layer and does not affect the PDs. Furthermore, by adopting the differential detection scheme as well, the required acceptable levels of cross-talk can be attained. The mounting configuration of the chips on a heat sink for this embodiment is similar to that illustrated in Figures 22A and 22B for the tenth embodiment 10. Alignment of the light paths along the optical axis of the lens in the TOSA package of Figure 27 is required, and pin allocation is the same as that for the eleventh embodiment.

It is noted that the configurations described in embodiments 8 to 13 can also be used in a stand alone manner, without employing the differential drive scheme. Specifically, the PD/WDM-filter, depicted in Figures 18B, 23, 26, 28 and 29, significantly reduces the level of optical cross-talk on its own, as well as reducing the overall cost of the optical module. For certain low speed applications where electrical cross-talk is not a major issue, this PD/WDM-filter chip together with the use of the improved optics is sufficient to realize the necessary performance specifications for an optical transceiver, and hence the use of a differential drive operation is not necessary and can be omitted. In addition, the mounting and packaging configurations, depicted in Figures 22, 25 and 27 can also be used without the differential drive scheme.

It is noted that the present invention is not only restricted to PON optical transceivers, but applies to all kinds of bi-directional transmission applications with WDM. In all the ONU transceivers described above, the transmitter has been a FP laser diode, as this is typical. However, DFB lasers may equally be used as the transmitter light source. Furthermore, the epitaxial layer structure of the chip on which the laser diode pair are formed can be based on either InGaAsP/InP or InAlGaAs/InP material systems. The photodetectors used in the optical transceiver module can be of either the P-I-N photodiode or avalanche photodiode type.

Although the focus has been on the 6-pin TOSA type packaging, a variety of packages with 5 or more pins may be used, depending upon the functional requirements. In addition, other aspects of the design are open to alternative configuration. For example, the monitor PD may or may not be slanted to avoid back reflection, the TIA and laser driver may be located be in one chip or in separate chips. Various modifications are possible with regard to the specific pin assignment and pin locations, and also to the detailed design of the chip locations within a package and on a heat sink.

## Claims

1. An optical transceiver comprising:

an optical port for coupling optical signals into and out of the optical transceiver;

a first optical transmitter for generating an optical output signal at a first wavelength in dependence on an electrical driving signal;

a first optical receiver for detecting an optical input signal at a second wavelength, the optical receiver generating an electrical received signal in dependence on the optical input signal; and,

means for compensating for an electrical error signal, the error signal being generated by the optical receiver in dependence on a portion of the optical output signal detected at the first wavelength and added to the electrical received signal.

2. An optical transceiver according to claim 1, wherein the compensating means comprises:

a second optical receiver for generating an electrical correction signal in dependence on a portion of the optical output signal detected at the first wavelength; and,

means for combining the electrical correction signal with the electrical received signal and error signal such that, in use, the electrical error signal is substantially compensated for.

3. An optical transceiver according to claim 1, wherein the compensating means comprises:

a second optical transmitter for generating an optical correction signal at the first wavelength in dependence on the electrical driving signal;

a second optical receiver for generating an electrical correction signal in dependence on the optical correction signal; and,

means for combining the electrical correction signal with the electrical received signal and error signal such that, in use, the electrical error signal is substantially compensated for.

4. An optical transceiver according to claim 2 or claim 3, wherein the combining means is a differential amplifier.

An optical transceiver any of claims 2 to 4, wherein the first optical receiver and the second optical receiver are substantially a matched pair, for equality of response.

6. An optical transceiver according to any of claims 3 to 5, wherein the first optical transmitter and the second optical transmitter are driven differentially by the electrical driving signal and the combining means is a summing amplifier.

7. An optical transceiver any of claims 3 to 6, wherein the first optical transmitter and the second optical transmitter are substantially a matched pair, for equality of signal generation.

8. An optical transceiver according to any preceding claim, wherein an optical transmitter comprises a laser diode.

9. An optical transceiver according to any preceding claim, wherein an optical receiver comprises a photodiode.

10. An optical transceiver according to any preceding claim, wherein the optical port comprises a wavelength division multiplexing (WDM) filter for spatial routing of the optical output signal at the first wavelength and the optical input signal at the second wavelength.

11. An optical transceiver according to claim 10, wherein the wavelength division multiplexing filter is a thin film filter disposed on a substrate adjacent an optical receiver.

12. An optical transceiver according to claim 11, wherein the wavelength division multiplexing filter and the optical receiver are located on an upper surface of a substrate, a lower surface of the substrate being coated to reflect light at the second wavelength.

13. An optical transceiver according to any preceding claim, further comprising an optical detector for monitoring the optical signal generated by an optical transmitter.

14. An optical transceiver according to claim 13, wherein the optical detector is disposed between the optical transmitter and an optical transceiver.

15. An optical transceiver according to claim 13 or claim 14, wherein the means for compensating for the electrical error signal comprises the optical detector and an

ectrical signal derived from it in dependence on a portion of the optical output signal from a transmitter.

16. An optical transceiver according to any preceding claim, wherein the first optical transmitter is located on a first substrate and the first optical receiver is located on a second substrate, the first and second substrates being disposed substantially perpendicular to each other.

17. An optical transceiver according to any of claims 1 to 15, wherein the first optical trar smitter is located on a first substrate and the first optical receiver is located on a second substrate, the first and second substrates being disposed at an angle of substantially 45 degrees to each other.

18. An optical triplexer transceiver comprising:

an optical transceiver according to any preceding claim;

a further optical receiver for detecting an optical input signal at a third wavelength, the further optical receiver generating a further electrical received signal in dependence on the optical input signal at the third wavelength; and,

a wavelength division multiplexing filter for spatial routing of the optical output signal at the first wavelength and the optical input signals at the second and third wavelengths.

19. An optical transceiver according to any preceding claim, wherein an optical signal has a wavelength within a range selected from a group including 1260nm to 1360nm, 1480nm to 1500nm and 1539nm to 1565nm.

20. A packaged optical transceiver comprising an optical transceiver according to any preceding claim packaged within a Transmitter Optical Sub-Assembly (TOSA) module.

21. A packaged optical transceiver according to claim 20, wherein a first electrical contact and a second electrical contact are circumferentially disposed on a base of the TOSA module at substantially 90 degrees to each other, the first electrical contact being connected to an optical transmitter within the module and the second electrical contact being connected to an optical receiver within the module.

22. An optical transceiver comprising:

an optical port for coupling optical signals into and out of the optical transceiver;

an optical transmitter for generating an optical output signal at a first wavelength in dependence on an electrical driving signal;

an optical receiver for detecting an optical input signal at a second wavelength, the optical receiver comprising a photodetector formed on a receiver substrate, the photodetector generating an electrical received signal in dependence on the optical input signal; and,

a wavelength division multiplexing (WDM) filter for routing the optical output signal from the transmitter to the optical port and for routing the optical input signal from the optical port to the receiver, the WDM filter comprising a thin film filter disposed on the receiver substrate, the receiver substrate disposed at an angle of substantially 45 degrees to a plane containing the transmitter.

23. An optical transceiver according to claim 22, wherein the photodetector and the thin film WDM filter are disposed on an upper surface of the receiver substrate and an optical coating that is reflective at the second wavelength is disposed on a lower surface of the substrate such that, in use, the optical input signal diffracted through the thin film filter and reflected by the optical coating towards the photodetector.

24. An optical triplexer transceiver, comprising an optical transceiver according to claim 23, the thin film WDM filter routing an optical input signal at a third wavelength towards another photodetector disposed on the upper surface of the receiver substrate, in use, the optical input signal at the third wavelength diffracted through the thin film filter and reflected by the optical coating on the lower surface of the substrate towards the other photodetector.

25. An optical triplexer transceiver, comprising an optical transceiver according to claim 23, wherein the receiver substrate having the photodetector and thin film WDM filter is disposed on an upper surface of another receiver substrate, another photodetector responsive to a third wavelength and another thin film WDM filter disposed on the upper surface of the other receiver substrate and an optical coating that is reflective at the third wavelength disposed on a lower surface of the other substrate, in use, the optical input signal at the second wavelength routed by the other thin film WDM filter towards the photodetector and an optical input signal at the third wavelength diffracted through the

er thin film filter and reflected by the optical coating on the lower surface of the other substrate towards the other photodetector.

26. An optical transceiver according to any of claims 22 to 25, wherein the receiver comprises a layer that absorbs light at the first wavelength.

27. An optical triplexer transceiver comprising:

an optical port for coupling optical signals into and out of the optical transceiver;

an optical transmitter for generating an optical output signal at a first wavelength in dependence on an electrical driving signal;

a first optical receiver for detecting an optical input signal at a second wavelength and a second optical receiver for detecting an optical input signal at a third wavelength, each of the first and second optical receiver comprising a photodetector formed on a receiver substrate, each photodetector generating an electrical received signal in dependence on the received optical input signal; and,

a wavelength division multiplexing (WDM) filter for routing the optical output signal from the transmitter to the optical port and for demultiplexing the optical input signal and routing the input signal at the second wavelength from the optical port to the first photodetector and for routing the input signal at the third wavelength from the optical port to the second photodetector, the WDM filter comprising a thin film filter disposed on a glass substrate, the glass substrate disposed between and substantially perpendicular to the two receiver substrates.

28. An optical triplexer transceiver according to claim 26, wherein the two receiver substrates and the WDM filter are disposed at an angle of substantially 45 degrees to a plane containing the transmitter.

29. An optical triplexer transceiver according to claim 26 or claim 27, wherein each of the first receiver and second receiver comprises a receiver substrate having a thin film WDM filter and a photodetector disposed on an upper surface of the receiver substrate and an optical coating on the a lower surface of the substrate, in use, each of the optical input signals at the second and third wavelength are routed by the WDM demultiplexer to their respective receiver, wherein the signal is diffracted through the thin film filter and reflected by the optical coating on the lower surface of the receiver substrate towards the photodetector.

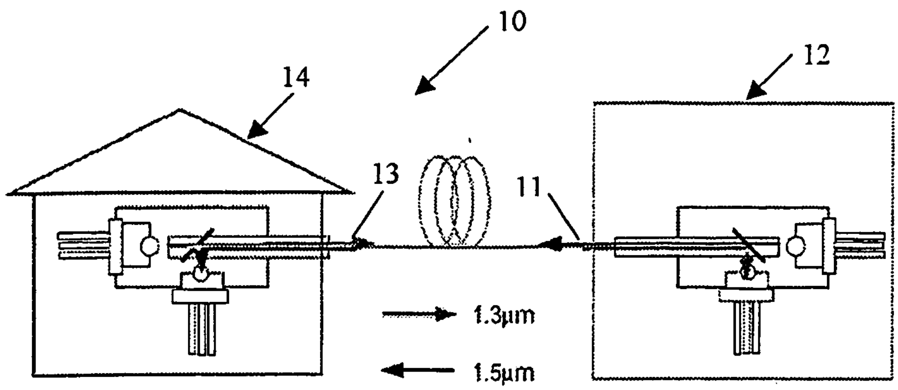
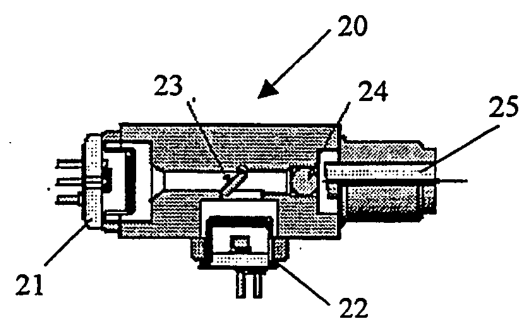
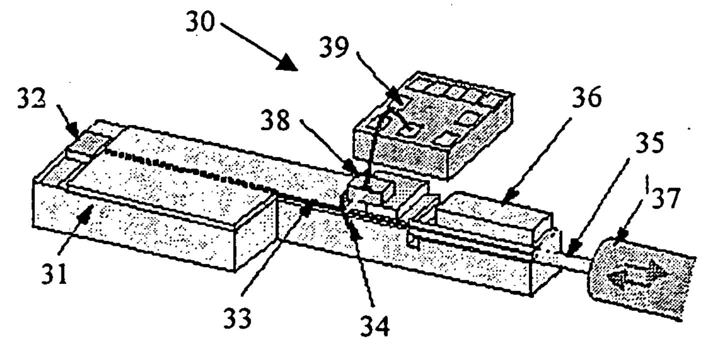



Fig 1



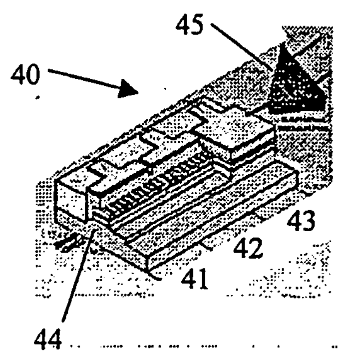

PRIOR ART

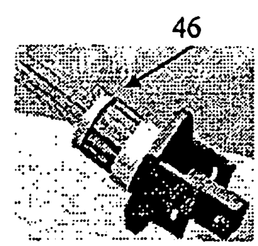
Fig 2




PRIOR ART

Fig 3




PRIOR ART

Fig 4A

Fig 4B

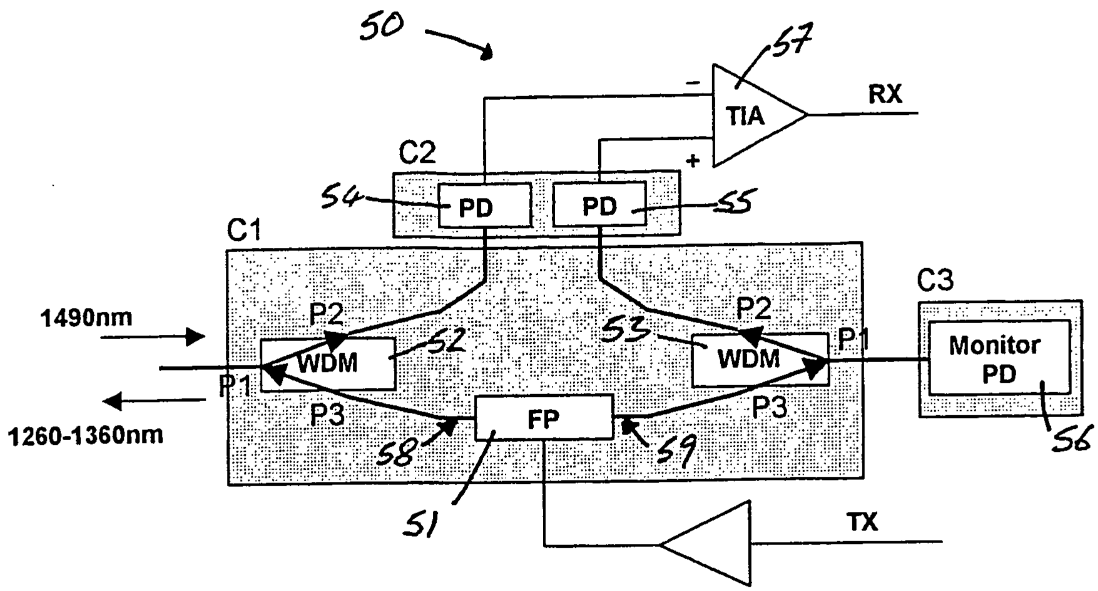

50
57
TIA
RX
C2
54
PD
PD
55
C1
C3
1490nm
P2
52
53
P2
P1
WDM
WDM
Monitor PD
P1
P3
FP
P3
1260-1360nm
58
59
56
51
TX

Fig 5

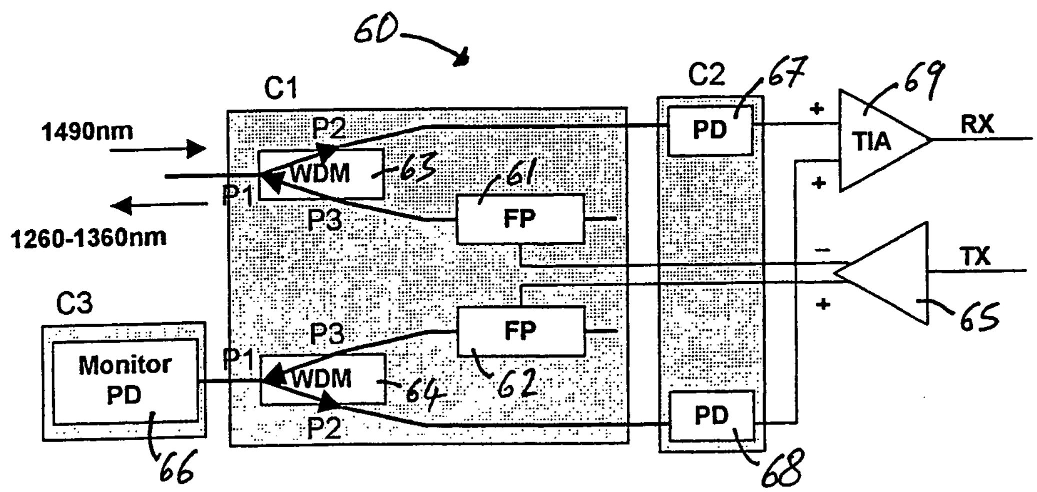

60
C1
C2
67
69
1490nm
P2
PD
TIA
RX
WDM
63
P1
61
1260-1360nm
P3
FP
TX
65
C3
P3
FP
Monitor PD
P1
WDM
64
62
P2
PD
66
68

Fig 6

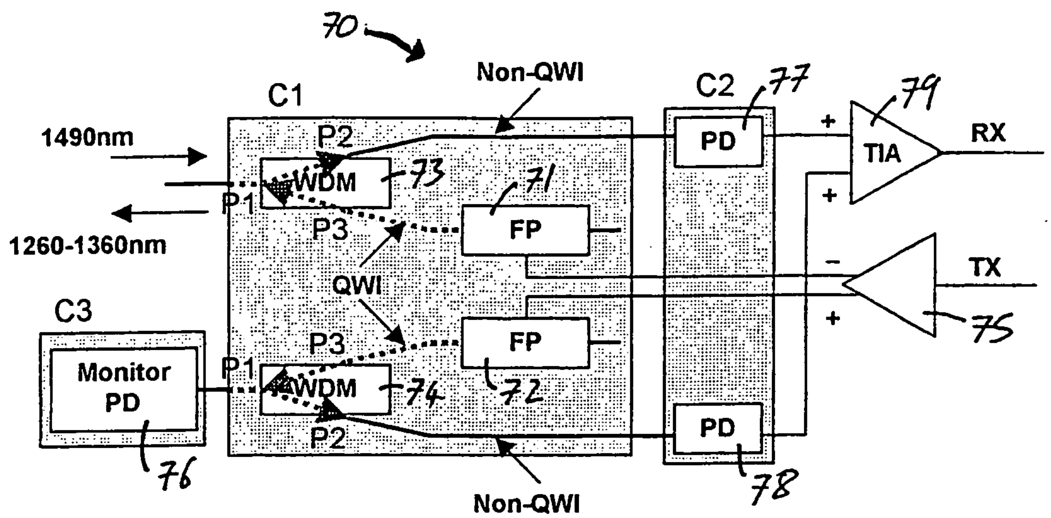

70
Non-QWI
C1
C2
77
79
1490nm
P2
PD
TIA
RX
WDM
73
71
P1
1260-1360nm
P3
FP
QWI
TX
C3
P3
FP
75
Monitor
PD
P1
WDM
74
72
P2
PD
76
78
Non-QWI

Fig 7

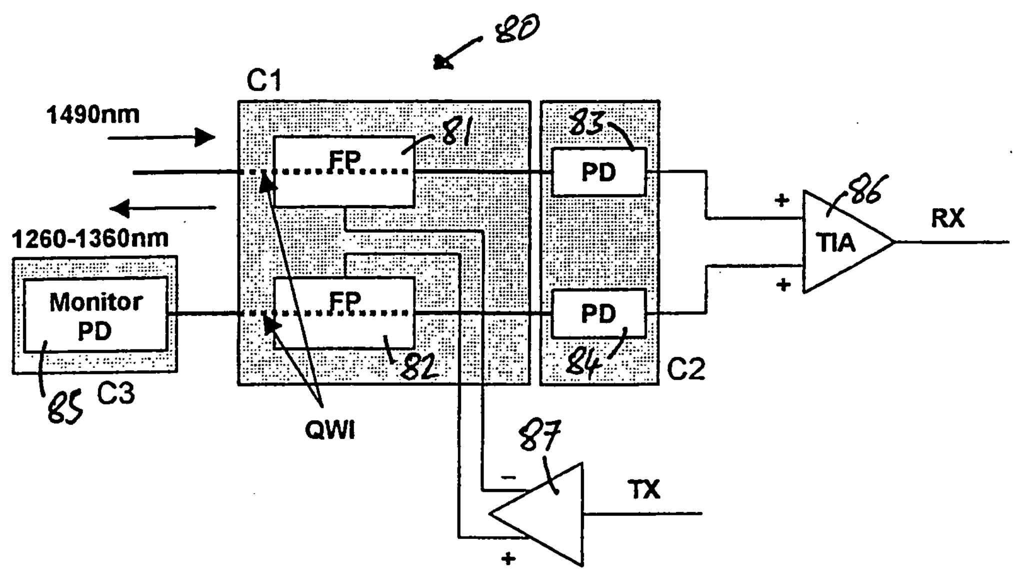

80
C1
1490nm
FP
81
83
PD
86
1260-1360nm
TIA
RX
Monitor
PD
FP
PD
82
84
C2
85
C3
QWI
87
TX

Fig 8

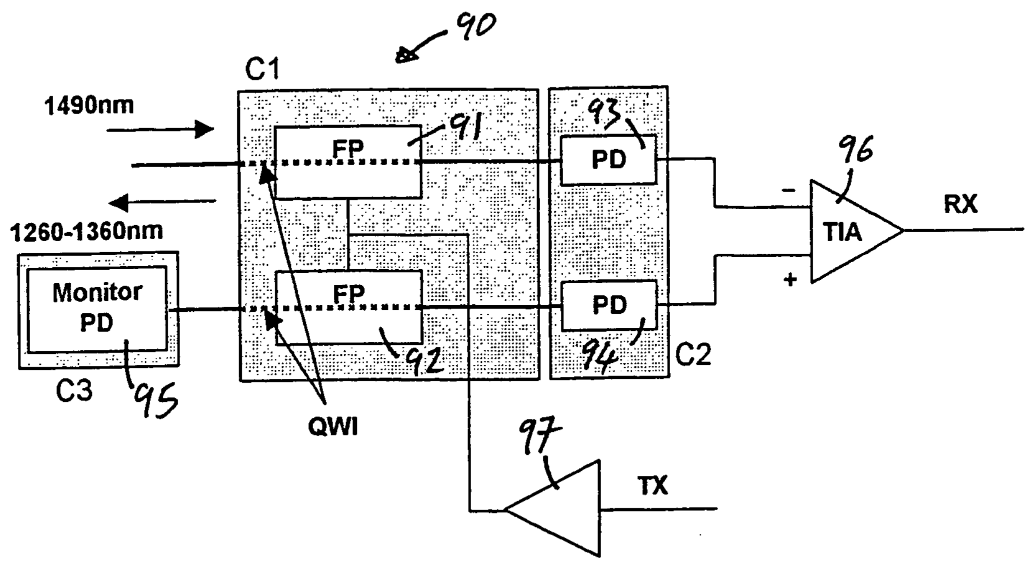

90
C1
1490nm
1260-1360nm
FP
FP
91
92
93
94
PD
PD
C2
96
TIA
RX
Monitor PD
C3
95
QWI
97
TX

Fig 9

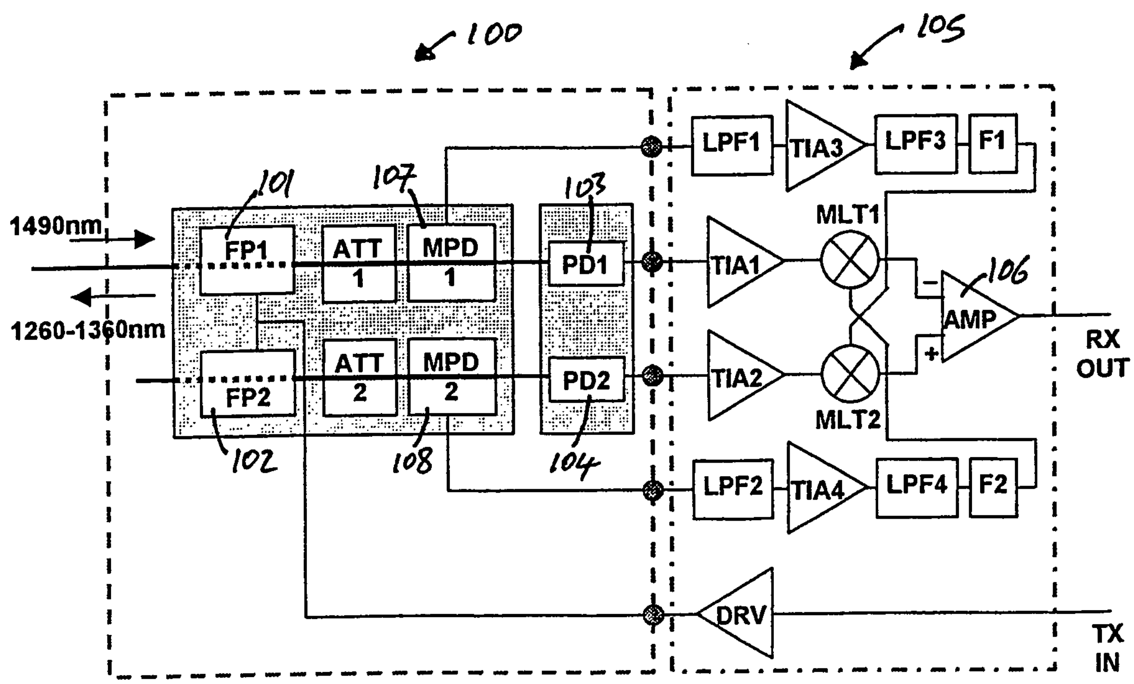

100
105
1490nm
1260-1360nm
FP1
FP2
101
102
ATT 1
ATT 2
MPD 1
MPD 2
107
108
PD1
PD2
103
104
LPF1
TIA3
LPF3
F1
MLT1
TIA1
TIA2
MLT2
AMP
106
RX OUT
LPF2
TIA4
LPF4
F2
DRV
TX IN

Fig 10

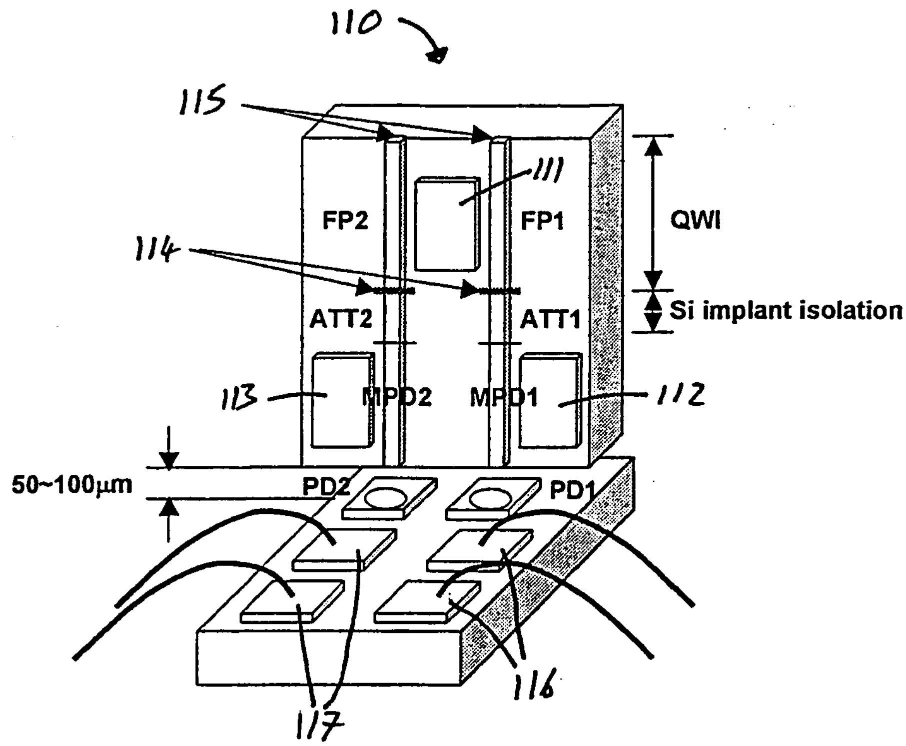

110
115
111
FP2
FP1
QWI
114
ATT2
ATT1
Si implant isolation
113
MPD2
MPD1
112
50~100μm
PD2
PD1
116
117

Fig 11

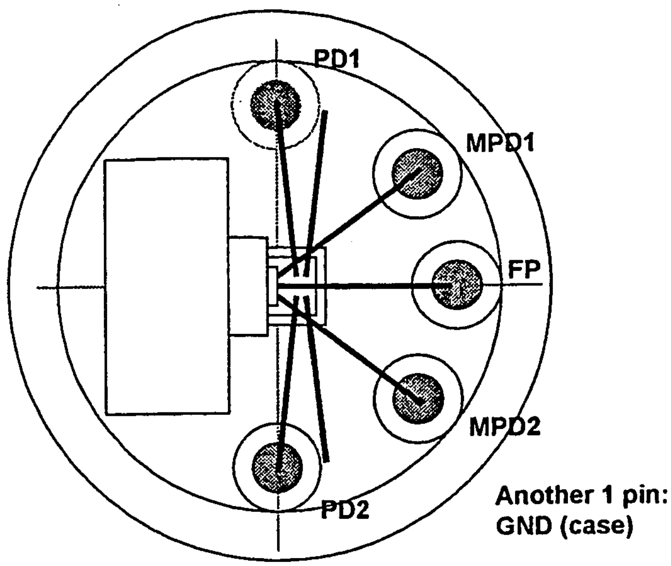



Fig 12A

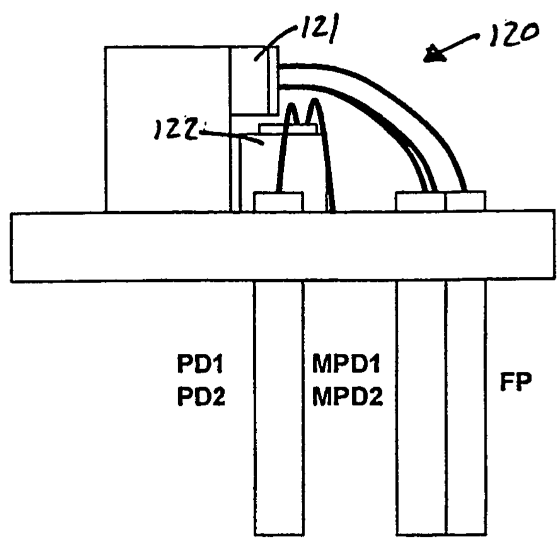



Fig 12B

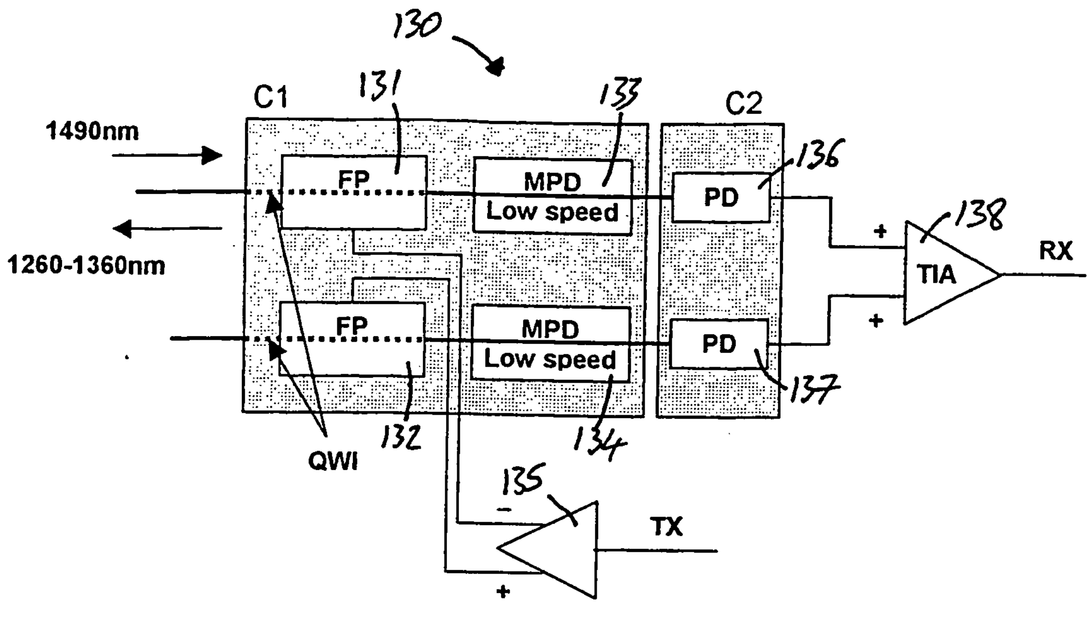

130
C1
131
133
C2
1490nm
FP
MPD
Low speed
PD
136
138
1260-1360nm
TIA
RX
FP
MPD
Low speed
PD
137
132
134
QWI
135
TX

Fig 13

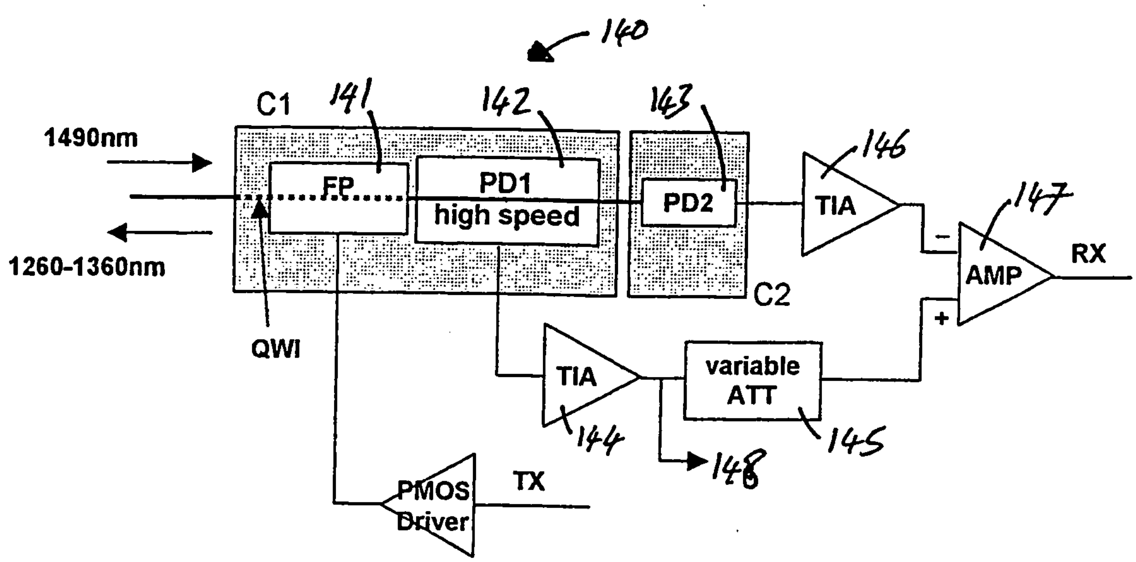

140
C1
141
142
143
1490nm
FP
PD1
high speed
PD2
TIA
146
147
1260-1360nm
AMP
RX
C2
QWI
TIA
variable
ATT
144
145
148
PMOS
Driver
TX

Fig 14

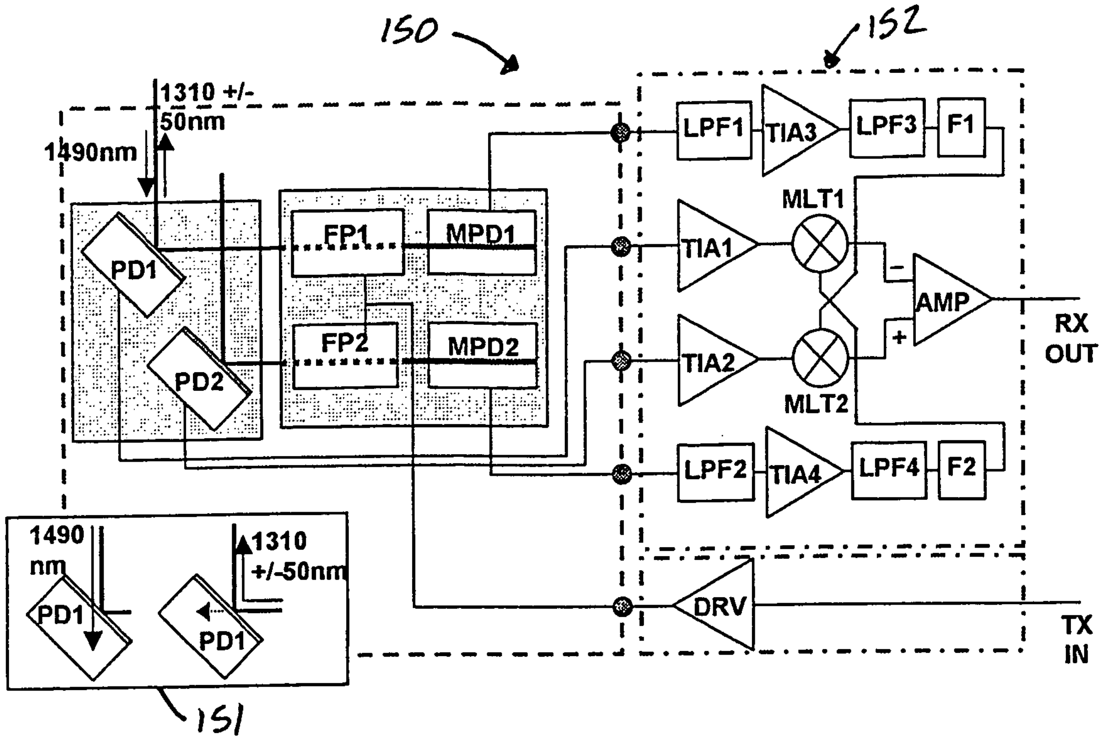

150
152
1310 +/-
50nm
1490nm
PD1
PD2
FP1
MPD1
FP2
MPD2
LPF1
TIA3
LPF3
F1
MLT1
TIA1
AMP
RX
OUT
TIA2
MLT2
LPF2
TIA4
LPF4
F2
1490
nm
1310
+/-50nm
PD1
PD1
DRV
TX
IN
151

Fig 15

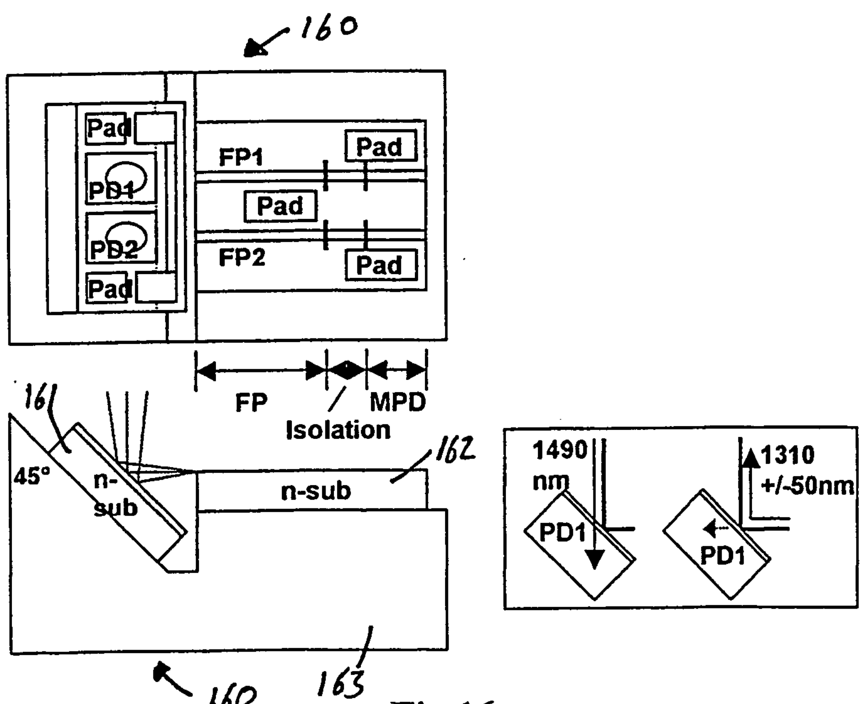

160
Pad
FP1
Pad
PD1
Pad
PD2
FP2
Pad
Pad
FP
Isolation
MPD
161
45°
n-
sub
n-sub
162
1490
nm
1310
+/-50nm
PD1
PD1
160
163

Fig 16

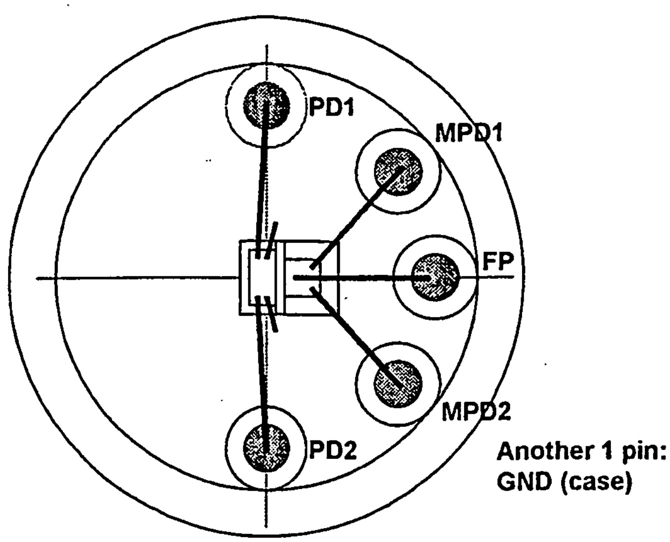



Fig 17A

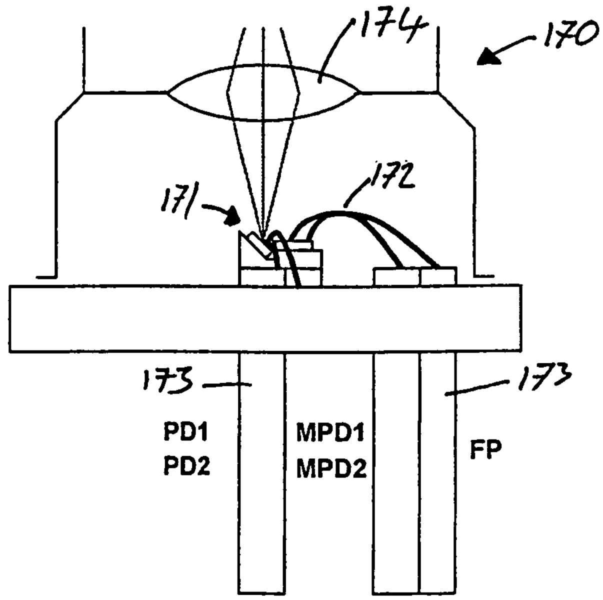



Fig 17B

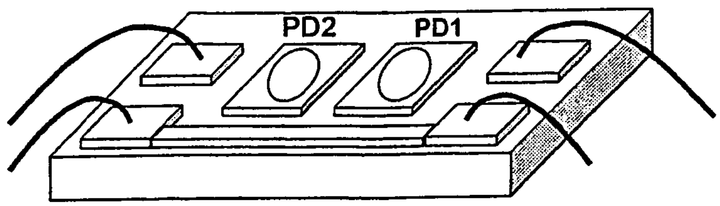



**Fig 18A**

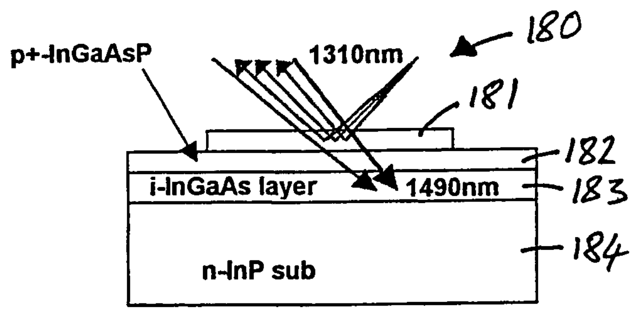



**Fig 18B**

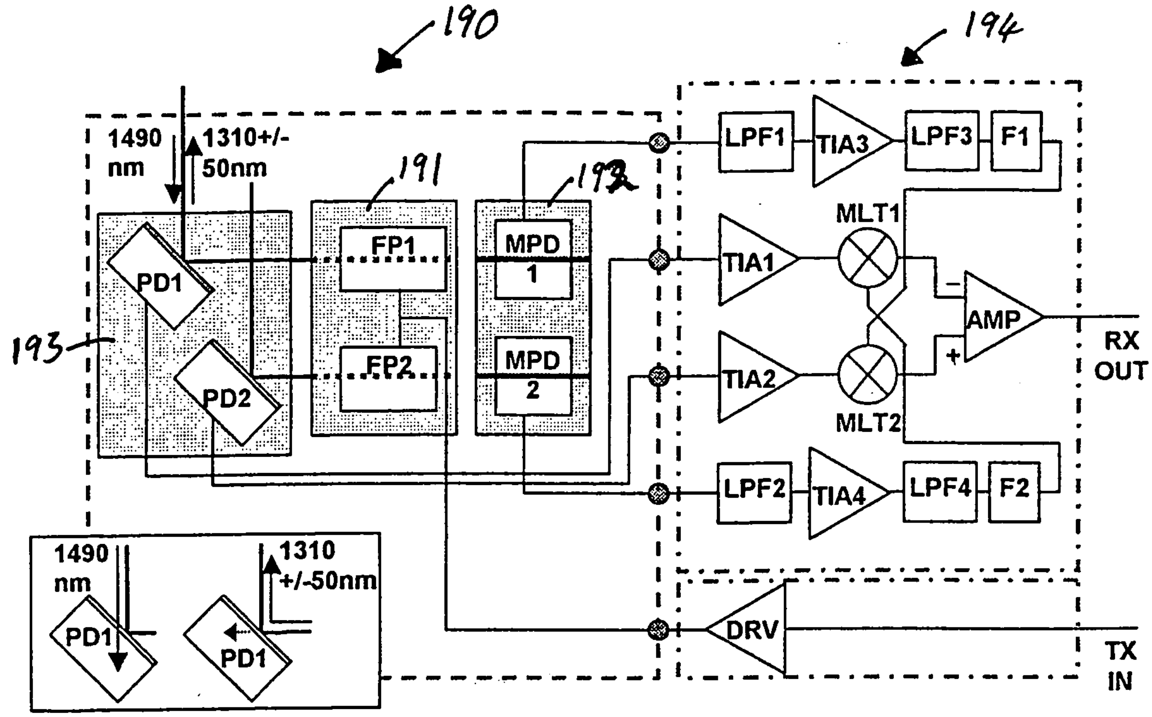

190
194
1490
nm
1310+/-
50nm
191
192
193
PD1
PD2
FP1
FP2
MPD
1
MPD
2
LPF1
TIA3
LPF3
F1
MLT1
TIA1
TIA2
MLT2
AMP
RX
OUT
LPF2
TIA4
LPF4
F2
DRV
TX
IN
1490
nm
1310
+/-50nm
PD1
PD1

Fig 19

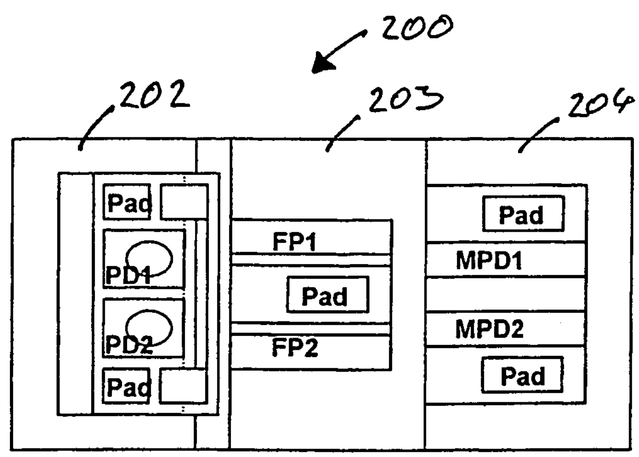



Fig 20A

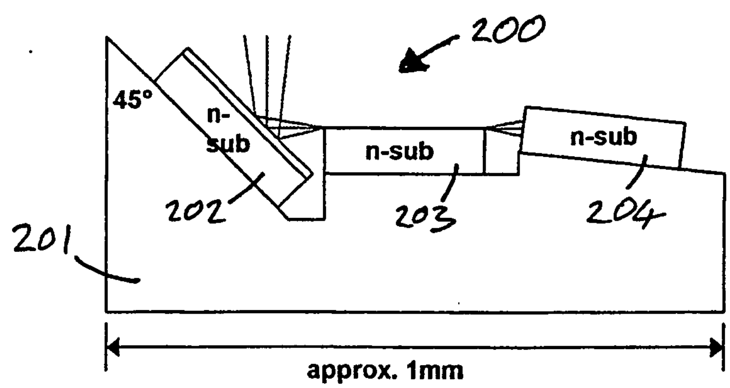



Fig 20B

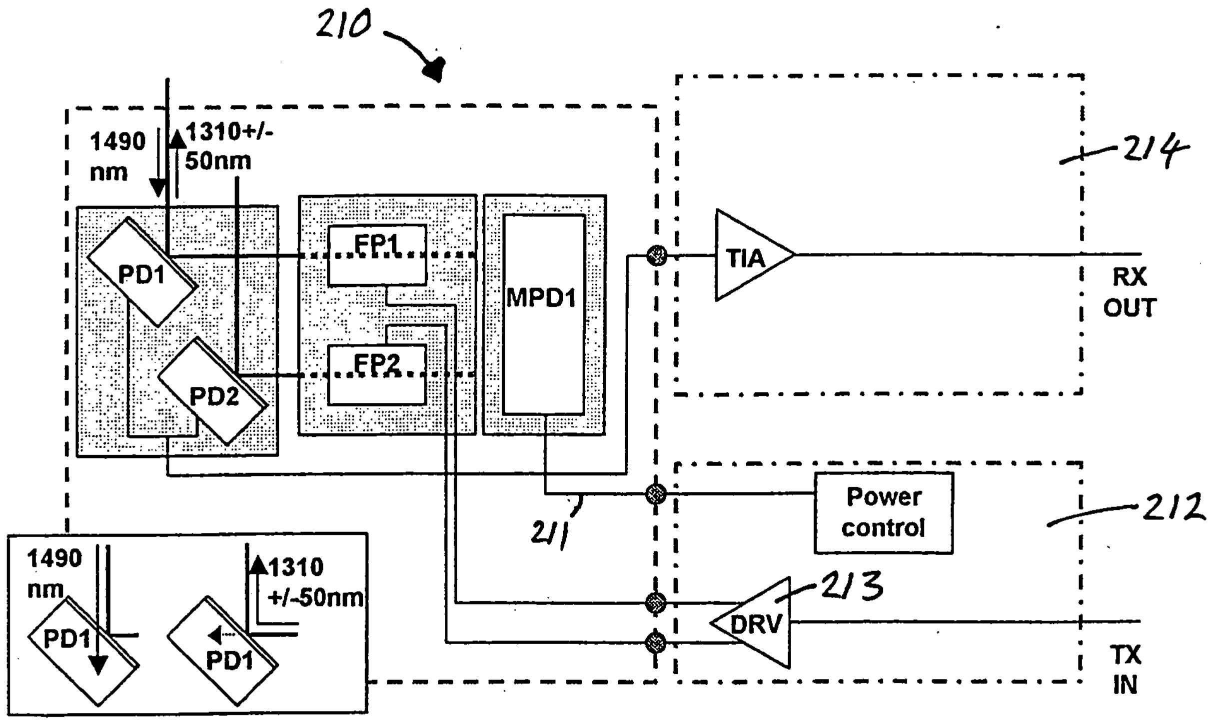

210
1490
nm
1310+/-
50nm
PD1
PD2
FP1
FP2
MPD1
TIA
RX
OUT
214
211
Power
control
212
213
DRV
TX
IN
1490
nm
PD1
1310
+/-50nm
PD1

Fig 21

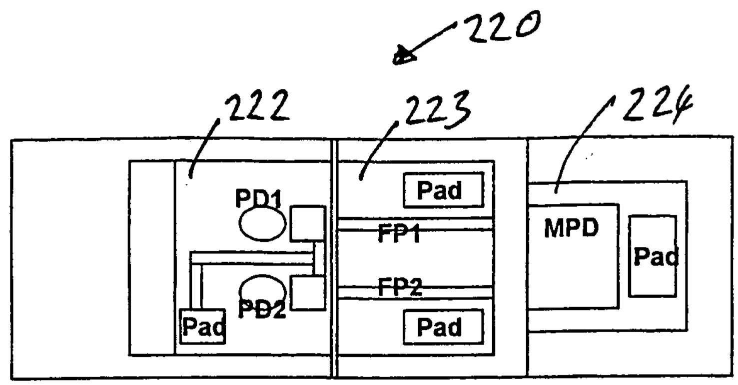



Fig 22A

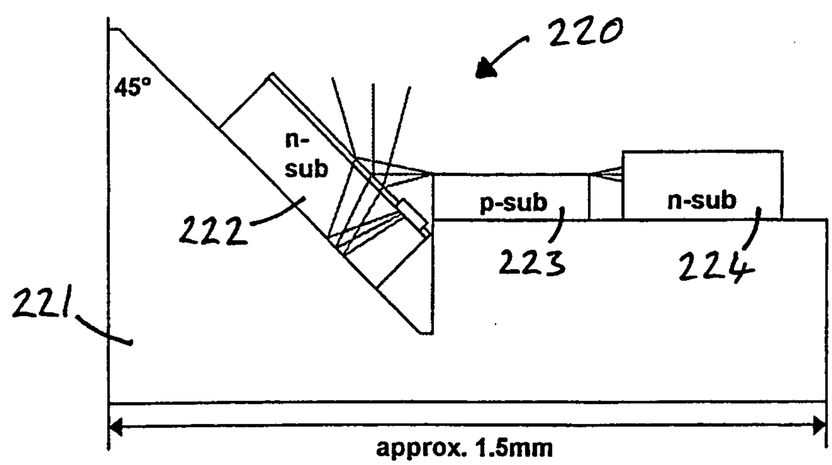



Fig 22B

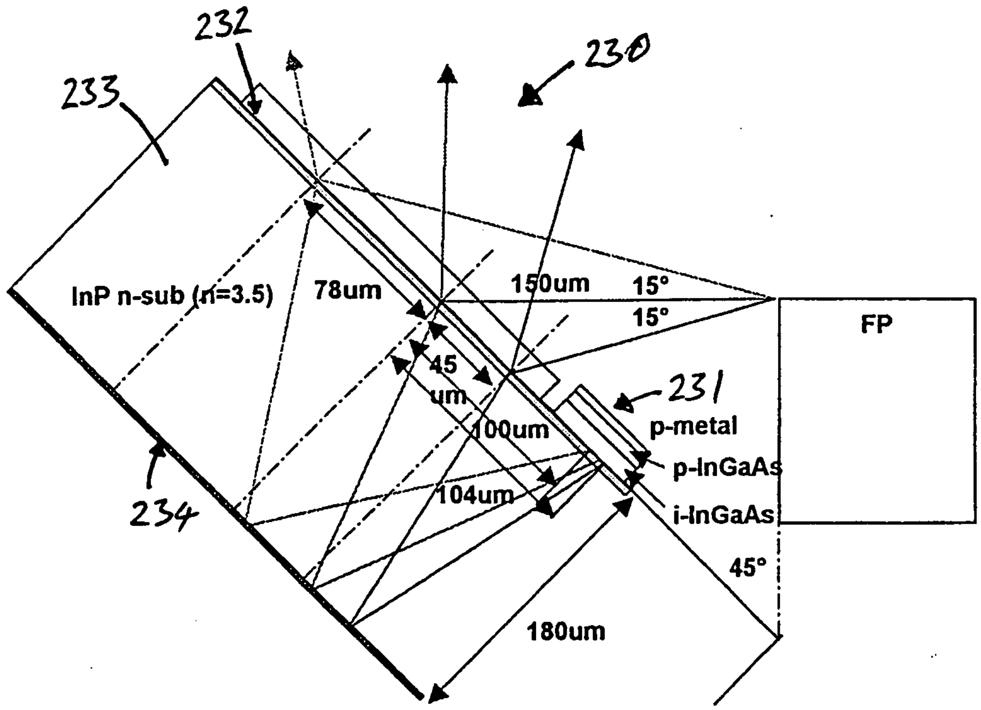

232
233
230
InP n-sub (n=3.5)
78um
150um
15°
15°
FP
45
um
231
p-metal
100um
p-InGaAs
104um
i-InGaAs
234
45°
180um

Fig 23

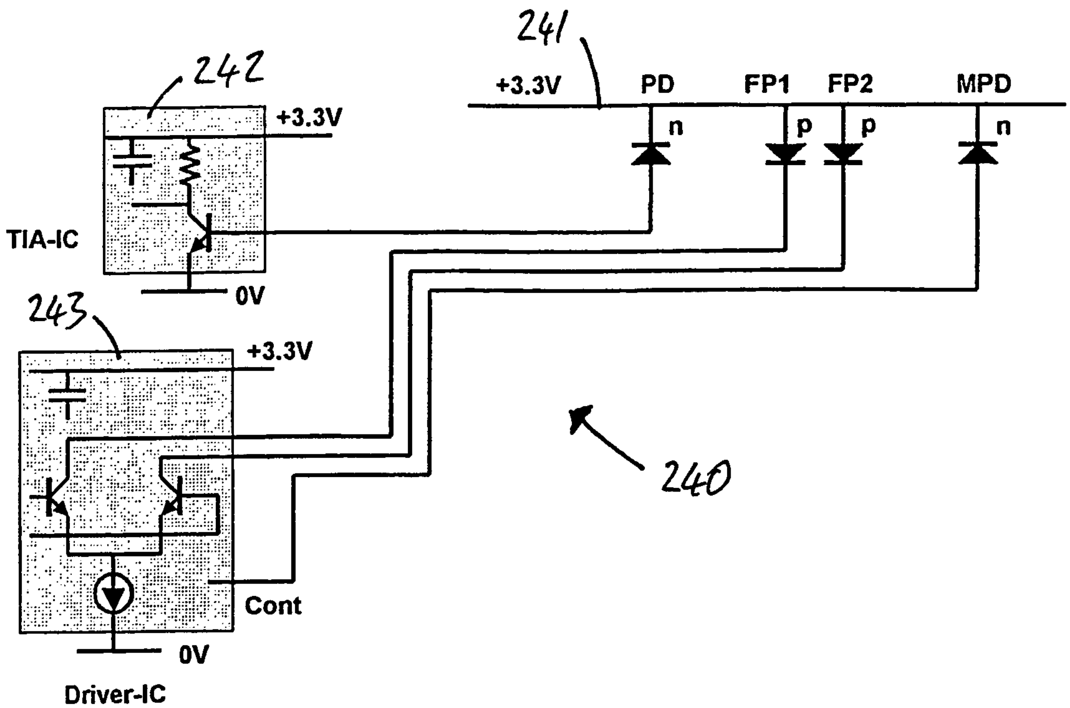

241
+3.3V
PD
FP1
FP2
MPD
n
p
p
n
242
+3.3V
TIA-IC
0V
243
+3.3V
Cont
0V
Driver-IC
240

Fig 24

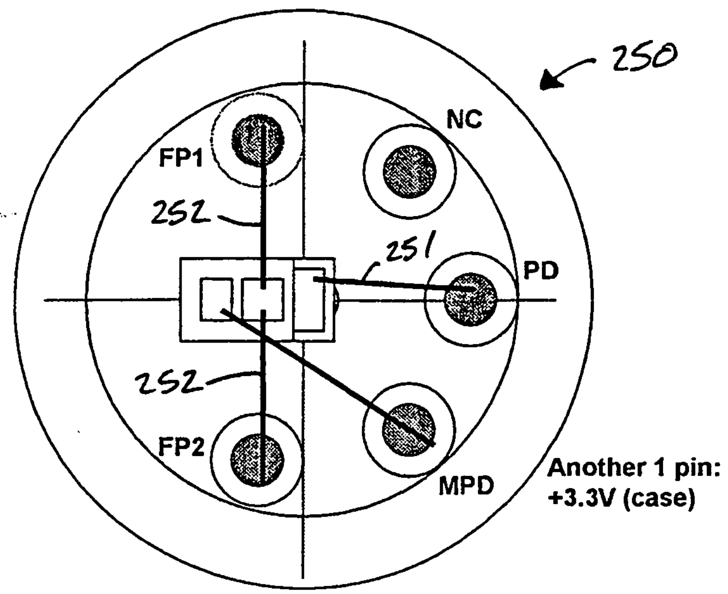



Fig 25A

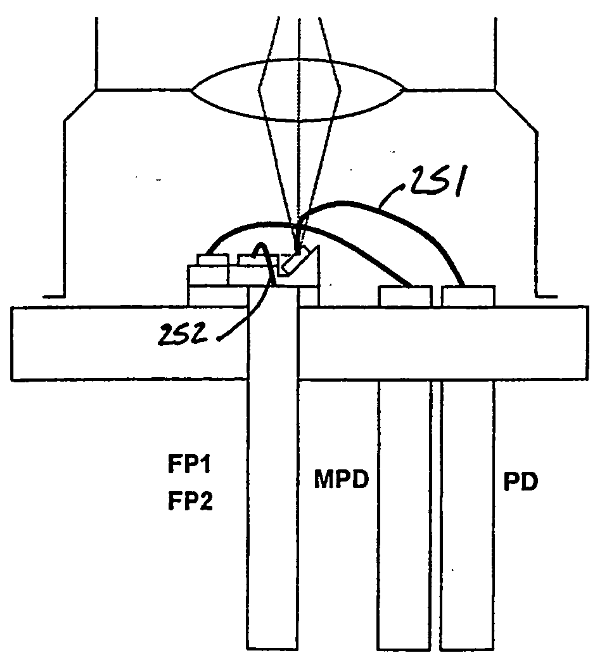



Fig 25B

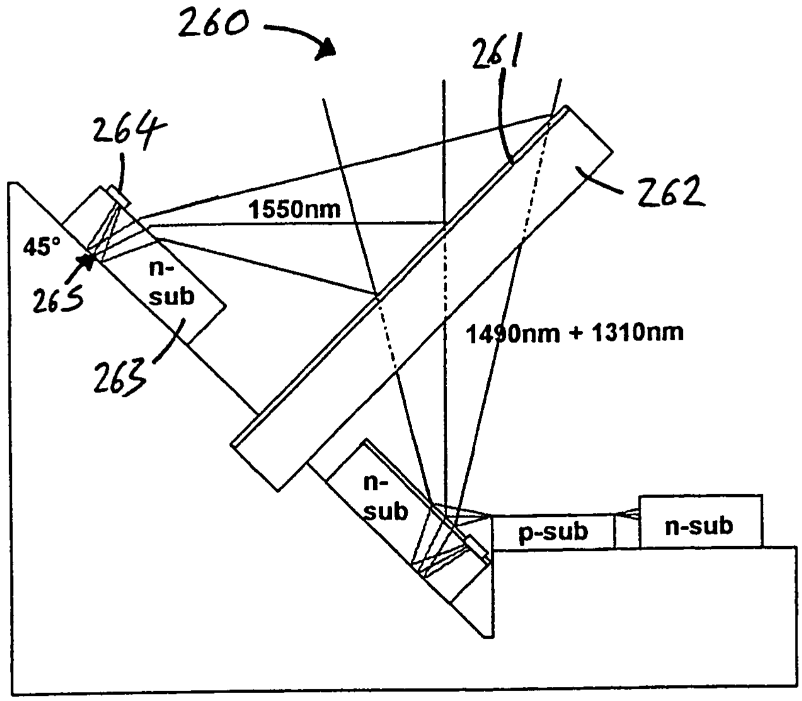

260
261
264
262
1550nm
45°
n-
sub
265
263
1490nm + 1310nm
n-
sub
p-sub
n-sub

Fig 26

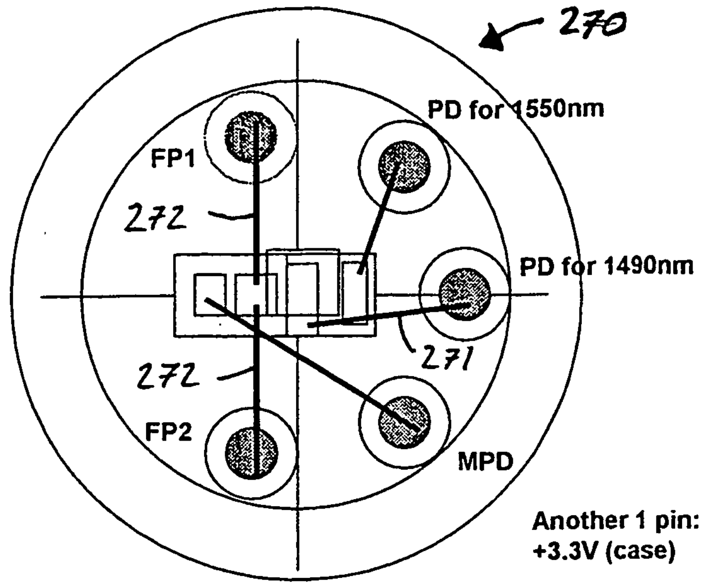



Fig 27A

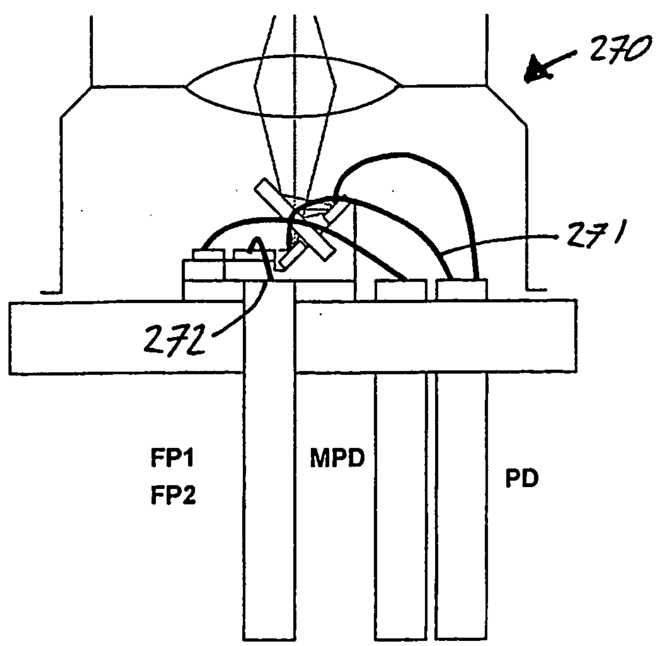
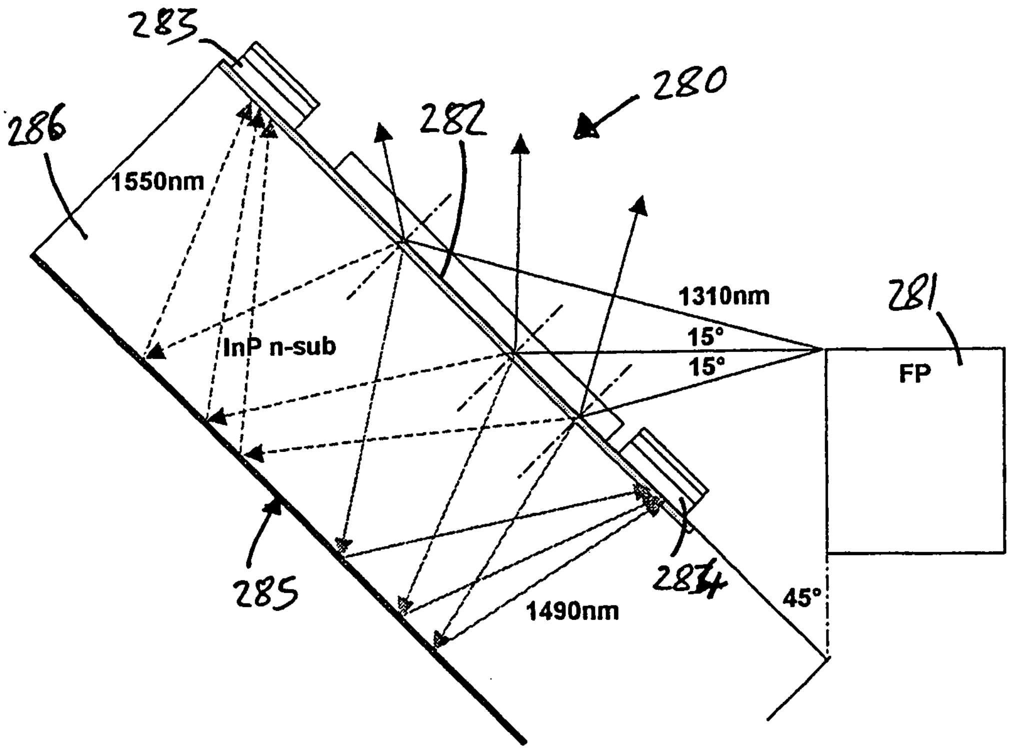



Fig 27B



283
280
286
282
1550nm
1310nm
281
15°
15°
FP
InP n-sub
285
284
1490nm
45°


Fig 28

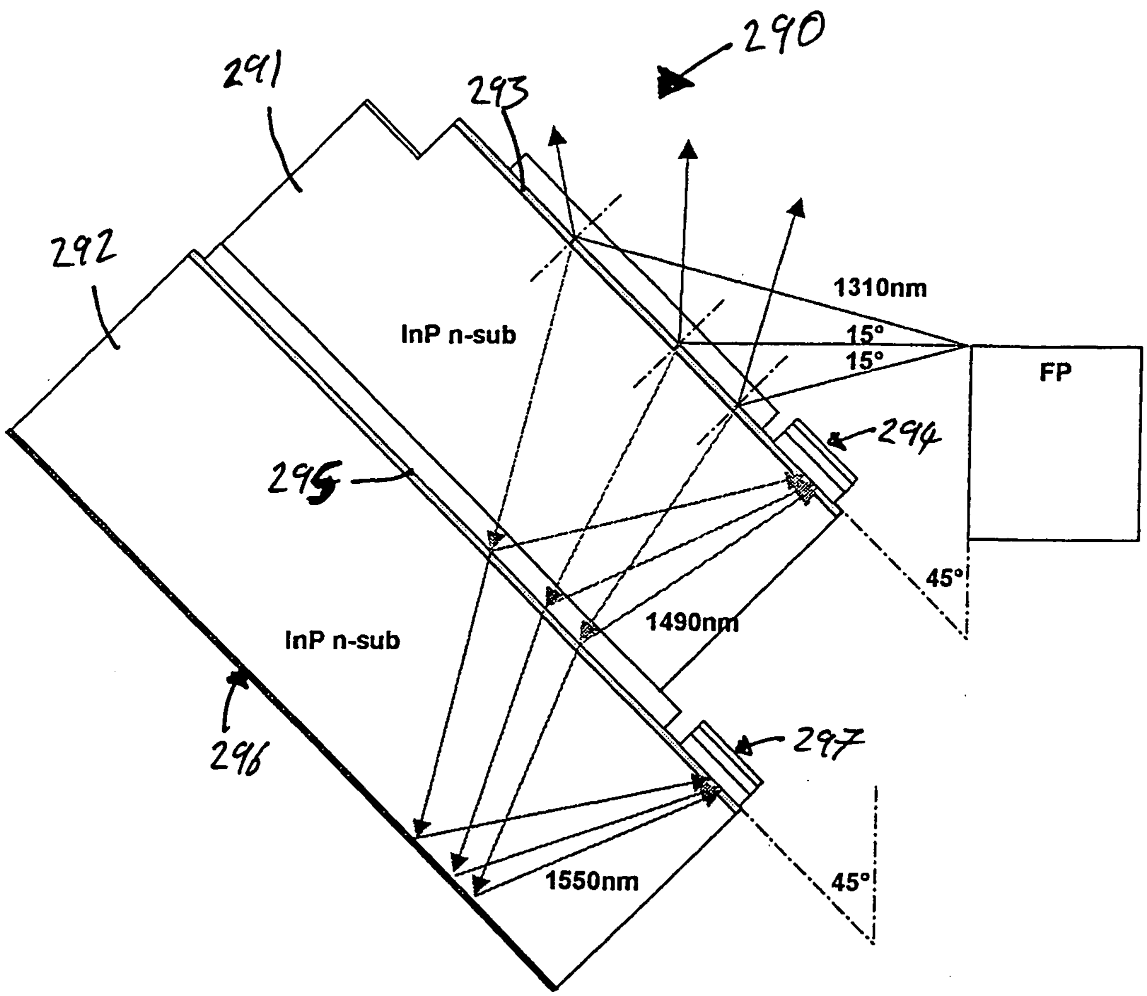

290
291
293
292
InP n-sub
1310nm
15°
15°
FP
294
295
45°
1490nm
InP n-sub
296
297
1550nm
45°

Fig 29

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

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10 February 2005 (10.02.2005)

PCT

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(30) Priority Data:
0317858.9 30 July 2003 (30.07.2003) GB

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(71) Applicant *(for MN only)*: **FINNIE, Peter, John** [GB/GB]; Broadgate House, Eldon Street, London EC2M 7LH (GB).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **KOJIMA, Keisuke** [JP/SG]; 23H Flora Road, #01-07, Huesca Block, Esyella Gardens, Singapore 509739 (SG). **NAKAMURA, Hiroshi** [JP/SG]; 5 Simei Street #06-02, East Point Green Tower 3C, Singapore 529892 (SG).

(74) Agent: **GILL JENNINGS & EVERY**; Boradgate Hosue, 7 Eldon Street, London EC2M 7LH (GB).

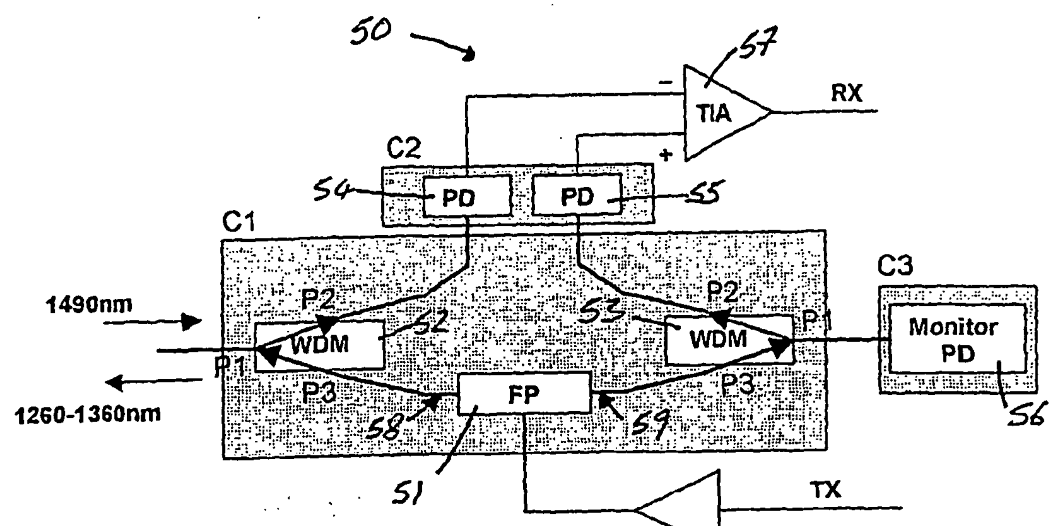
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

**Published:**
— *with international search report*

*[Continued on next page]*

(54) Title: OPTICAL TRANSCEIVER WITH REDUCED OPTICAL CROSS-TALK BETWEEN TRANSMITTER AND RECEIVER




(57) Abstract: A optical transceiver that employs matched pairs of photonic components, including laser diodes, photodiodes and filters, and differential electrical compensation with common mode rejection to achieve a high effective level of optical and electrical isolation between signals at the transmitter waveband and signals at the receiver waveband. A novel configuration of WDM filter also improves isolation and both techniques are extended to the triplexer transceiver. Innovative arrangement of the components and contacts permits the realization of a very compact packaged transceiver unit.

WO 2005/013517 A3

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

**(88) Date of publication of the international search report:**
28 April 2005

*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

# INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB2004/003333

**A. CLASSIFICATION OF SUBJECT MATTER**
IPC 7 H04B10/24 G02B6/42

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04B G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, INSPEC

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category ° | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | EP 1 107 485 A (NIPPON ELECTRIC CO) 13 June 2001 (2001-06-13)<br>column 2, paragraph 17 - column 3, paragraph 18<br>column 4, paragraph 32 - column 5, paragraph 46<br>figures 3,4<br>----- | 1,2,4, 8-10,13, 15,19 |
| X | US 5 317 441 A (SIDMAN STEVEN B) 31 May 1994 (1994-05-31)<br>column 1, line 37 - column 2, line 4<br>column 3, line 15 - column 4, line 43<br>figures 2-4<br>----- | 1,2,4,5, 8-10,13, 15,19 |
| | -/-- | |

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 10 November 2004 | 17. 02. 2005 |

| Name and mailing address of the ISA | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,<br>Fax: (+31-70) 340-3016 | Hadziefendic, I |

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

| Category ° | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X<br><br>A | WO 03/017534 A (IVRY RAANAN ; BROADLIGHT LTD (IL)) 27 February 2003 (2003-02-27)<br>page 2, paragraph 4<br>page 5, paragraph 1 - paragraph 4<br>page 5, paragraph 7 - page 6, paragraph 1<br>page 6, paragraph 6 - paragraph 7<br>----- | 1,8,9<br><br>4,19 |

# INTERNATIONAL SEARCH REPORT

ıational application No.
PCT/GB2004/003333

**Box II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

**Box III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-10, 13-15, 19

**Remark on Protest**

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-10, 13-15, 19

   Optical transceiver comprising a second optical transmitter and a second optical receiver

   ---

2. claims: 11-12

   Optical transceiver comprising a thin film filter disposed on a substrate adjacent an optical receiver

   ---

3. claims: 16-17, 22-23

   Optical transceiver whereing the optical transmitter is located on a first substrate and the first optical receiver is located on a second substrate

   ---

4. claims: 18, 24-29

   Optical triplexer transceiver comprising an optical transceiver and a further optical receiver for detecting an input signal at a third wavelength

   ---

5. claims: 20-21

   Packaged optical transceiver comprising an optical transceiver packaged with a Transmitter Optical Sub-Assembly module

   ---

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB2004/003333

| Patent document cited in search report | | Publication date | Patent family member(s) | | Publication date |
|---|---|---|---|---|---|
| EP 1107485 | A | 13-06-2001 | JP | 2001160778 A | 12-06-2001 |
| | | | EP | 1107485 A2 | 13-06-2001 |
| | | | US | 2001002864 A1 | 07-06-2001 |
| US 5317441 | A | 31-05-1994 | NONE | | |
| WO 03017534 | A | 27-02-2003 | WO | 03017534 A2 | 27-02-2003 |